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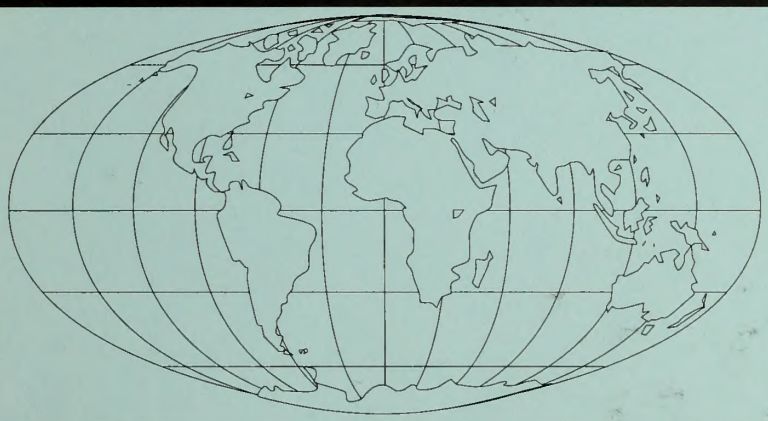

a report to the Director

September 1991

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BUREAU OF LAND MANAGEMENT
Wyoming State Office
P.O. Box 1828
Cheyenne, Wyoming 82003

September 12, 1991

TO: Director

FROM: Chairman, Satellite Positioning Technologies Work Group
Associate State Director, Wyoming

SUBJECT: A Report on Satellite Positioning Technologies

In compliance with the request of the Director. dated September 6, 1990, the satellite positioning work group submits this report on satellite positioning technologies.

The members of the work group appreciate the challenge, the assignment, and the fine cooperation displayed by a large number of people who contributed to the completion of this report.

The use of satellite positioning is an exciting new technology that will have a significant impact on Bureau programs. This report reflects the level of knowledge of satellite positioning systems held by Bureau personnel and sets forth what the task force believes is a reasonable course for its future.

The recommendations, while somewhat optimistic. comply fully with current U.S. policy regarding the future of satellite positioning contained within the 1990 Federal Radio Navigation Plan.

It is the SPT work group's firm recommendation that the Bureau Director assign overall responsibility for implementation to the AD, Support Services, WO (700), with overall technical support provided by the Service Center and training support provided by the PTC.

Following approval of the GPS strategy by the Director, the states should begin to factor GPS funding requirements within their AWP requests. WO (700) should ensure that the requests are appropriate within modernization, configuration, technology, and funding constraints and incorporate strict implementation instructions for the states within WO AWP advices.

J. William Eikenberry

118: 88055515

SATELLITE POSITIONING SYSTEM
Work Group Report

by

Bureau of Land Management

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TABLE OF CONTENTS

SATELLITE POSITIONING TECHNOLOGY **1**
EXECUTIVE SUMMARY 1
INTRODUCTION 1
BACKGROUND 2
FINDINGS 8
- Analysis of Current Uses and Needs 8
  - Current and Future Uses 8
  - Applicability to BLM Programs and Mission 9
    - High Precision Applications 11
    - Medium Precision Applications 11
    - Low Precision Applications 11
  - Recent Field Tests for Resource Applications 12
    - Colorado State Office Efforts 12
    - Wyoming GPS Operational Development Examples 13
  - Detailed Application Examples 13
    - Unauthorized Use Investigations and Documentation 13
    - Monitoring Sites 14
    - Road and Trail Location or Layout 14
  - Costs and Savings 15
  - Feasibility of BLM Implementation 16
- Analysis of Equipment 16
  - Equipment on Hand 16
  - Equipment Needs 16
- Radio Flight Following 16
  - Introduction 16
  - What is RDSS? 17
  - Situation 17
- Current Methods in Acquisition of Equipment 18
- Current Training Situation 18
  - Training Complexities 18
  - Availability of GPS Training 18
  - Evaluation of Current GPS Training 19
- Current Level of Interagency Cooperation 19

RECOMMENDATIONS 19
- Acquisition Strategy 19
  - Implementation Needs 19
  - Existing Procurement Options 20
  - Implementation Plan/Procurement Strategy 20
  - Funding Strategy 20
  - Acquisition for Remaining Implementation Requirements 21
- Establish Base Control Monumentation and Permanent Base Stations 21
- Radio Flight Following 21
- Location and Level of Support 22
- Training 22
  - Identifying BLM GPS Users 22
  - GPS Course Content 23
- Interagency Cooperation 24
  - General 24
  - Training 24
  - Data and Equipment Acquisition, Data Maintenance, Area Nets 24

GLOSSARY **27**

CONTENTS

APPENDIXES

APPENDIX A — Radio Determination Satellite Service **29**
APPENDIX B — Satellite Positioning Technologies Questionnaire **41**
APPENDIX C — Discussion on Global Positioning System (GPS) Applications for BLM **49**
APPENDIX D — GIS Resource Data Integration and GPS **57**
APPENDIX E — Draft GPS Course Outline **75**

FIGURES

FIGURE 1 — GPS System Segments **3**
FIGURE 2 — Constellation of Deployed Satellites **4**
FIGURE 3 — Navstar GPS Operational Constellation **5**
FIGURE 4 — GPS Operational Control System **6**
FIGURE 5 — Global Positioning Systems **9**
FIGURE 6 — Levels of GPS Accuracy **10**
FIGURE 7 — GPS Signal **11**
FIGURE 8 — GPS Matrix **23**
FIGURE 9 — Proposed GPS Courses **24**

SATELLITE POSITIONING TECHNOLOGY

EXECUTIVE SUMMARY

New and remarkable positioning and communications technology from the age of satellites is now available for wide application. Its promise and potential blending for BLM purposes will virtually apply to all functions and will gradually change methods of operation. Although space based technologies have been in use in BLM to a minor extent for many years, the coming-of-age of the NAVSTAR GLOBAL POSITIONING SYSTEM (Navigation Satellite Timing and Ranging, or GPS) dramatically points up an enormous operational resource from Satellite Positioning Technology (SPT).

Of all agencies in the Federal Government, BLM is in the top two or three in diversity of use. Uses range from aircraft flight tracking through archeological site location and production verification to specialized cadastral surveys. The list encompasses any function which uses location or electronic communication. Recognizing the need for leading edge efficiencies in adopting and adapting SPT, BLM management formed the SPT Work Group to:

— investigate uses and current and projected progress of SPT,

— recommend management policies for acquisition, training, and involvement in interagency SPT strategic planning.

Significant management attention factors have emerged from the SPT Work Group analysis:

— While there are some limitations in the use of SPT, both man-made and natural, SPT has come of age and that BLM should move quickly and decisively to fully implement its use.

— Education and training in the interpretation and evaluation of on-the-ground results is a critical requirement.

— Hardware/software procurements should be consolidated to reduce acquisition costs.

— Full cooperation with other agencies and active leadership involvement in national activities should be aggressively pursued (i.e., data exchange formats, standards and specification development, base station implementation, training, etc.).

— Data standards and the documentation necessary to attach reliability or accuracy to the coordinates derived from GPS technology must be a high priority.

— GPS is the prime SPT which will be used in the BLM; however, other SPT components should be considered, particularly with respect to real-time communications.

— Research and development in providing SPT capabilities and in hardware/software generation is well advanced and generally in the purview of other public and private entities; applied research, development, and implementation for specialized and combined BLM functions should be accomplished by BLM, e.g., HAZMAT location, drill pad location, and LIS/GIS interfacing.

— Integration of SPT for some BLM users may require the services (contractual) of outside sources of consultation.

This report overviews the SPT world with emphasis on GPS. It strongly advocates the use of SPT bureau-wide while also recognizing some limitations. It notes a simplicity of use, but also points out complexities in need of management direction. Volumes of scientific and technical information exist as to the theory and application of SPT. Very little of that type of data is included. The BLM SPT bridge described here is an attempt to bring the area of present and future capabilities together with BLM user needs and operations.

INTRODUCTION

In order for the BLM to continue an active leadership role in the identification of potential uses, technology application, and implementation of space-based satellite positioning and communications systems, the Director established a work group to review potential applications beyond current uses and provide him with strategies and recommendations for future BLM action - the incorporation of 21st century space-based positioning technology into its operations. The work group was lead by F. William Eikenberry, Associate State Director of Wyoming, and consisted of 10 members from various functional areas within the BLM.

The work group established a strategy plan that was approved by the Assistant Director for Support Services. The plan included the development of a survey format that was used to interview field and headquarters personnel on their knowledge and use of SPT as well as the kind of equipment currently being used. It also included studies by individual work group members on SPT equipment and uses.

The results of this study is the basis of this report, which discusses the SPT systems and other technology, results of the personal interviews and work group studies, and recommendations for further Bureau actions.

Growing satellite positioning technologies in the BLM's 1990s field land management activities will have as much impact as the computer technology did in the 1980s. It should complement both GIS/LIS and the expanding modernization effort in BLM. As the price of GPS receivers continues to fall and the relative ease of use increases, the BLM will institutionalize its use in every day field activities. The BLM has an opportunity to plan for the optimum growth of this technology. Modern resource and land management requires the identification and measurement of complex point, boundary, and area relationships, often times with variable levels of precision and accuracy, for use with new forms of automation such as the BLM's modernization efforts. Satellite positioning technologies have the capability to provide reliable geographic positioning for our future needs.

The Navigation Satellite Timing and Ranging (NAVSTAR) Global Positioning System (GPS), managed by the U.S. Air Force, will replace the U.S. Navy's Navigation Satellite System (Transit System) for military and civilian navigational needs. The GPS uses 21 NAVSTAR satellites and 3 spares to provide worldwide 3-dimensional (3D) positioning. Currently there are enough NAVSTAR satellites to provide 2D coverage full-time and 3D for part of a day. Full 24 hour per day, 3D coverage is scheduled for 1993. Most BLM applications should use the more accurate 3D positioning that requires four satellites to determine positions. The BLM Cadastral Survey has been using GPS since 1988 using receivers available from the Cadastral Equipment Cache.

The BLM's Aviation Program has combined both positional LORAN systems with commercial communication satellites to track the location of aircraft (see page 61). The system is called flight following and can reduce the time to locate a downed aircraft from a few days to minutes. Flight following technology can be added to our ground field vehicles, especially fire and law enforcement vehicles, providing the dispatcher with both communications and locational capabilities. This should provide for quicker response time to emergencies and act to enhance the capabilities of our field crews.

BACKGROUND

The primary Satellite Positioning Technology (SPT) is based on the Global Positioning System (GPS) which is a relatively new technology providing a tool that can be used to determine a precise location anywhere on the surface of the earth. The GPS was first developed for military applications as a guidance system for aircraft and ships. In 1983 the first commercial GPS receivers were developed for precise positioning.

The U.S. Government is funding the entire system. The concept behind GPS is relatively simple though some of the practical details are complicated. The GPS is a radio navigation system in which radio signals are sent from a constellation of navigational satellites. The signals are picked by GPS receivers which use the satellite data to produce the three dimensional positions: longitude, latitude, and the height of the receiver.

The system consists of the following three segments: (See Figure 1.)

— the space segment;
— the control segment; and
— the user segment.

The space segment, when completed, will consist of 24 NAVSTAR (Navigation Satellite Time and Ranging) satellites. At this time there are 15 operational satellites, and by 1993 there will be 24 satellites, of which 21 will be operational, and three will be orbiting spares, one in every other orbit. The satellites are deployed in six planes inclined 55 degrees from the equator, at an orbital altitude of 20,180 km. (10,900 nautical miles, or 12,550 land miles). (See Figures 2 & 3.). Each satellite completes a full orbit in 12 hours.

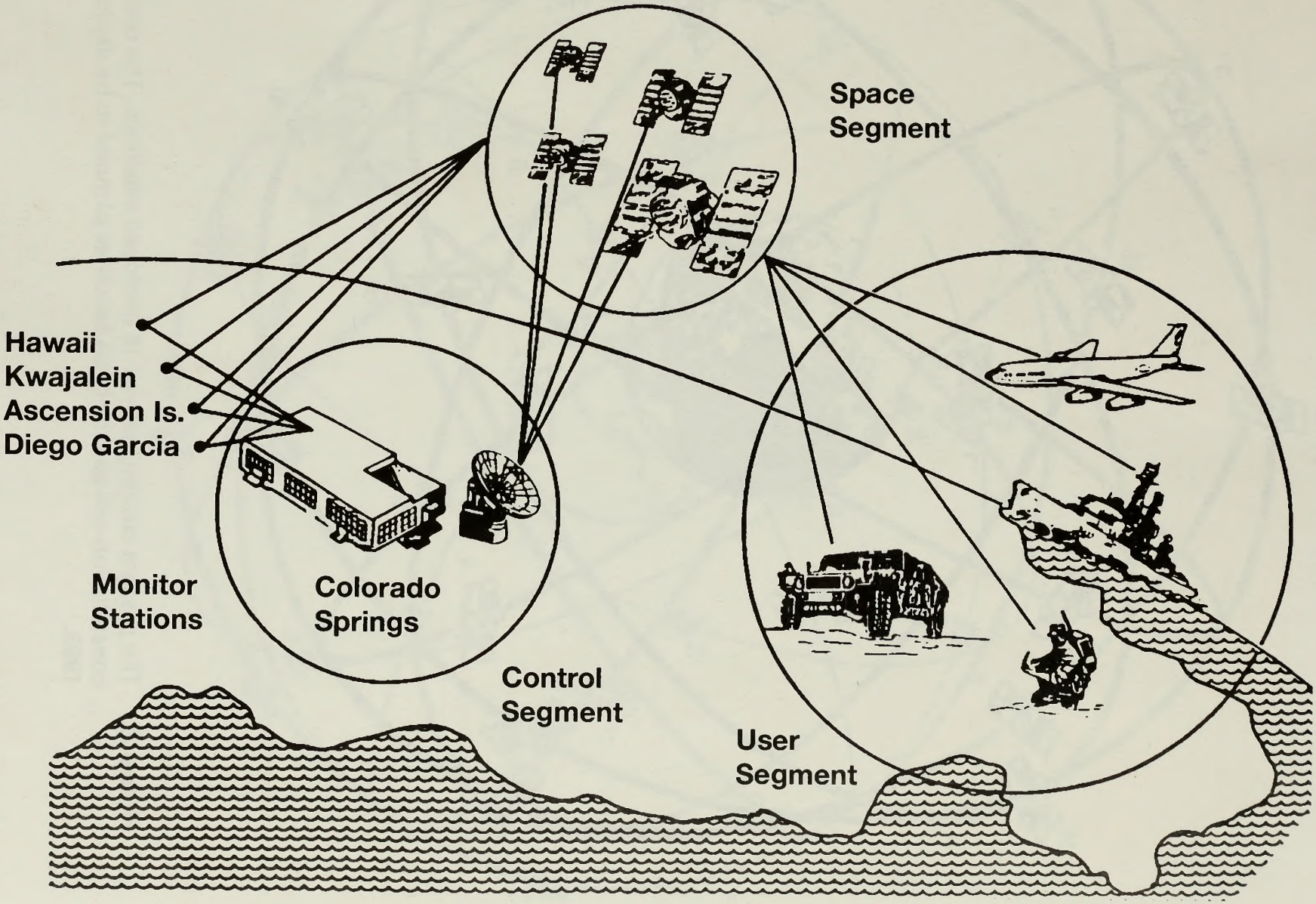
The control segment consists of five stations around the world that monitor and communicate with the satellites. The master control station is at the Consolidated Space Operations Center at Falcon Air Force Base, in Colorado. The other four control stations are at Ascension Island, Hawaii, Kwajalein atoll, and Diego Garcia. (See Fig. 4.).

The user segment consists of people using different types of receivers to collect satellite data and determine the three dimensional positions.

The 24 satellites that will orbit the earth are considered flying control points. GPS positioning is based on triangulation. The instantaneous X, Y, and Z coordinates (or longitude, latitude, and altitude) of each satellite are broadcast by radio signal and received by a GPS receiver. Because the X, Y, and Z coordinates of each satellite are known, the coordinates of the ground point (receiver) can be determined. The NAVSTAR satellites transmit precisely timed radio signals using atomic clocks that gain or lose one second every 300,000 years. By

Figure 1

GPS System Segments



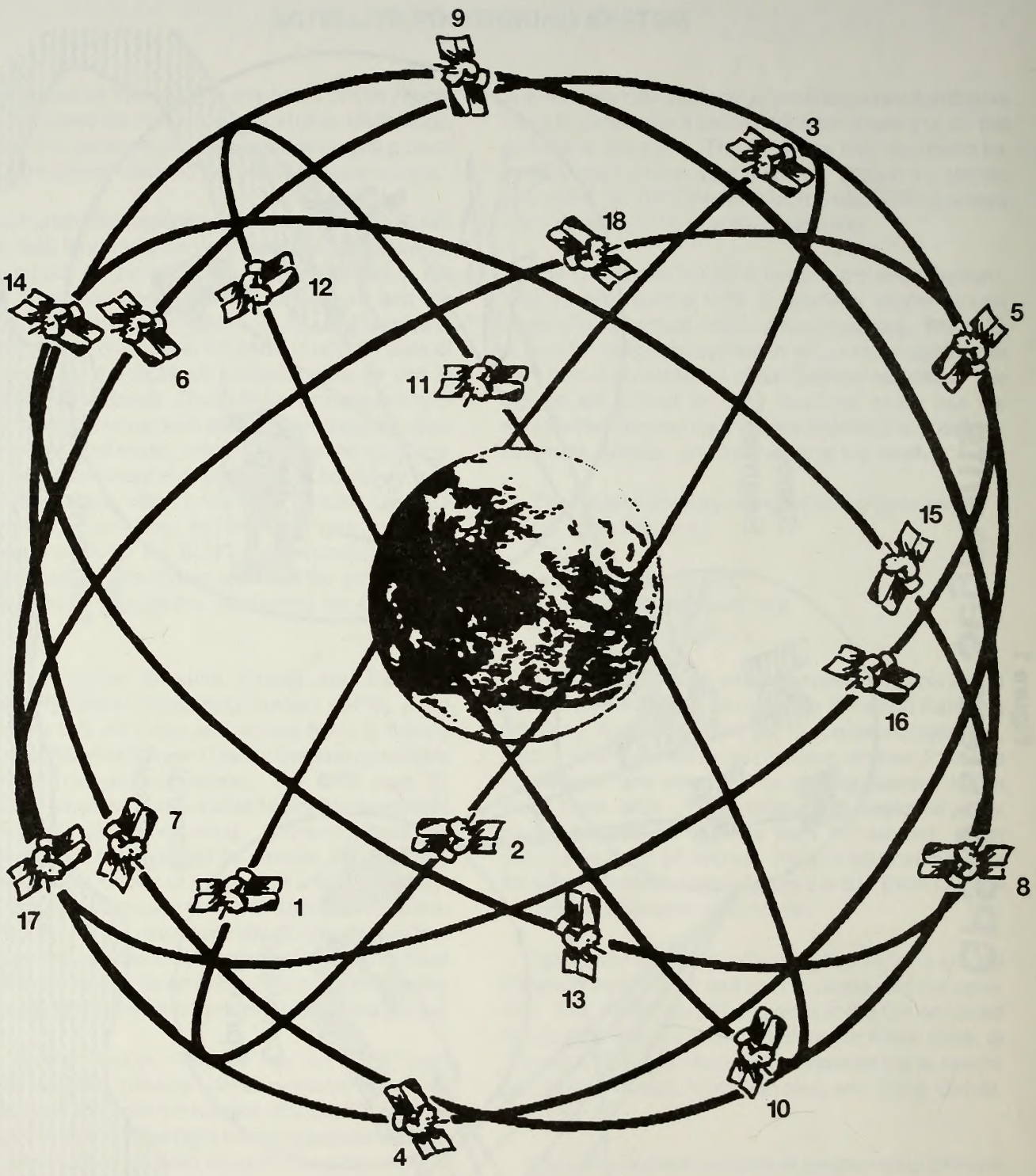


Figure 2: The present constellation of 16 deployed satellites. The complete constellation will consist of 24 satellites planned to be deployed by 1993.

Figure 3

The Navstar GPS Operational Constellation

(*21 Satellites + 3 Active Spares*)

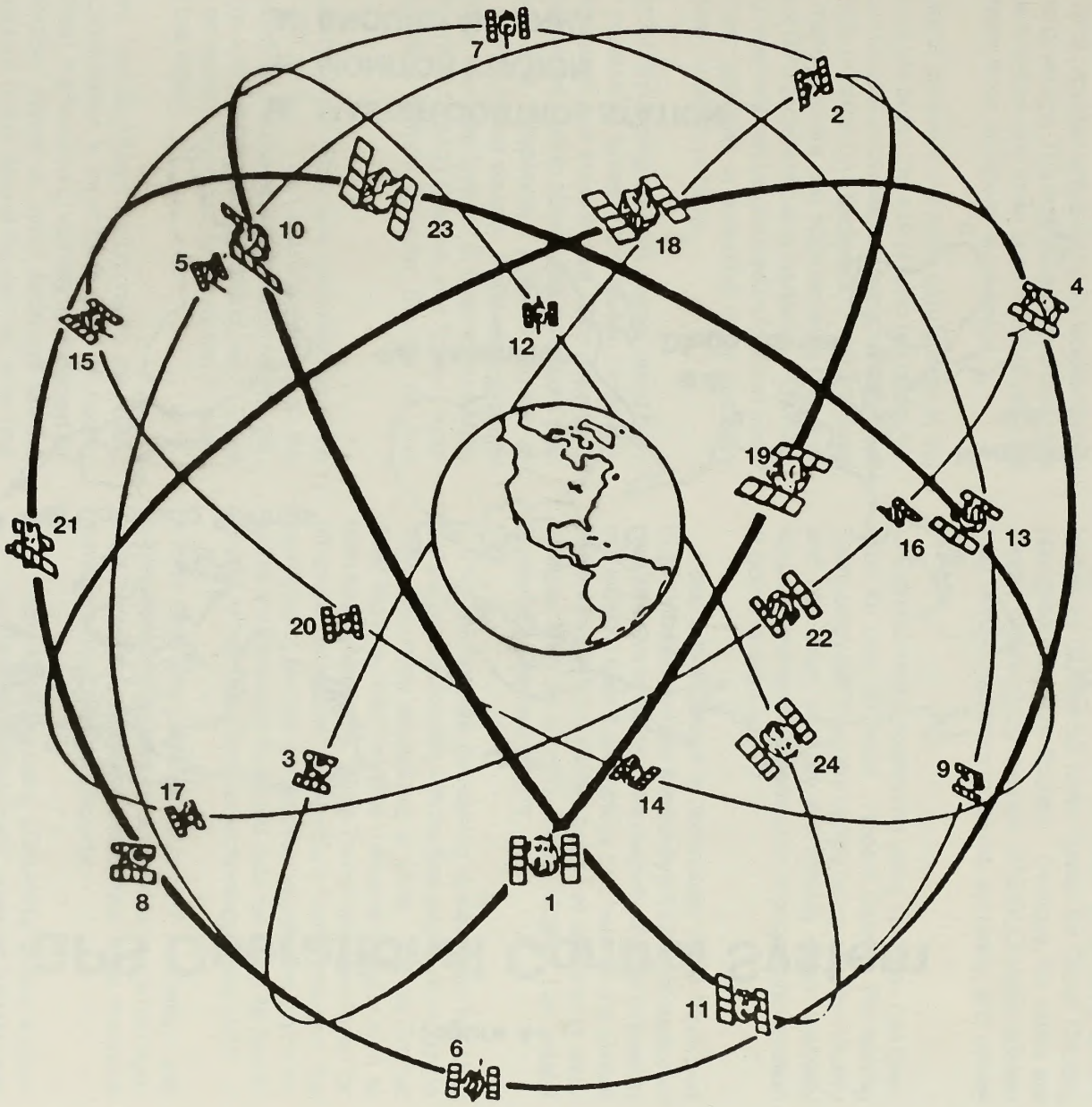
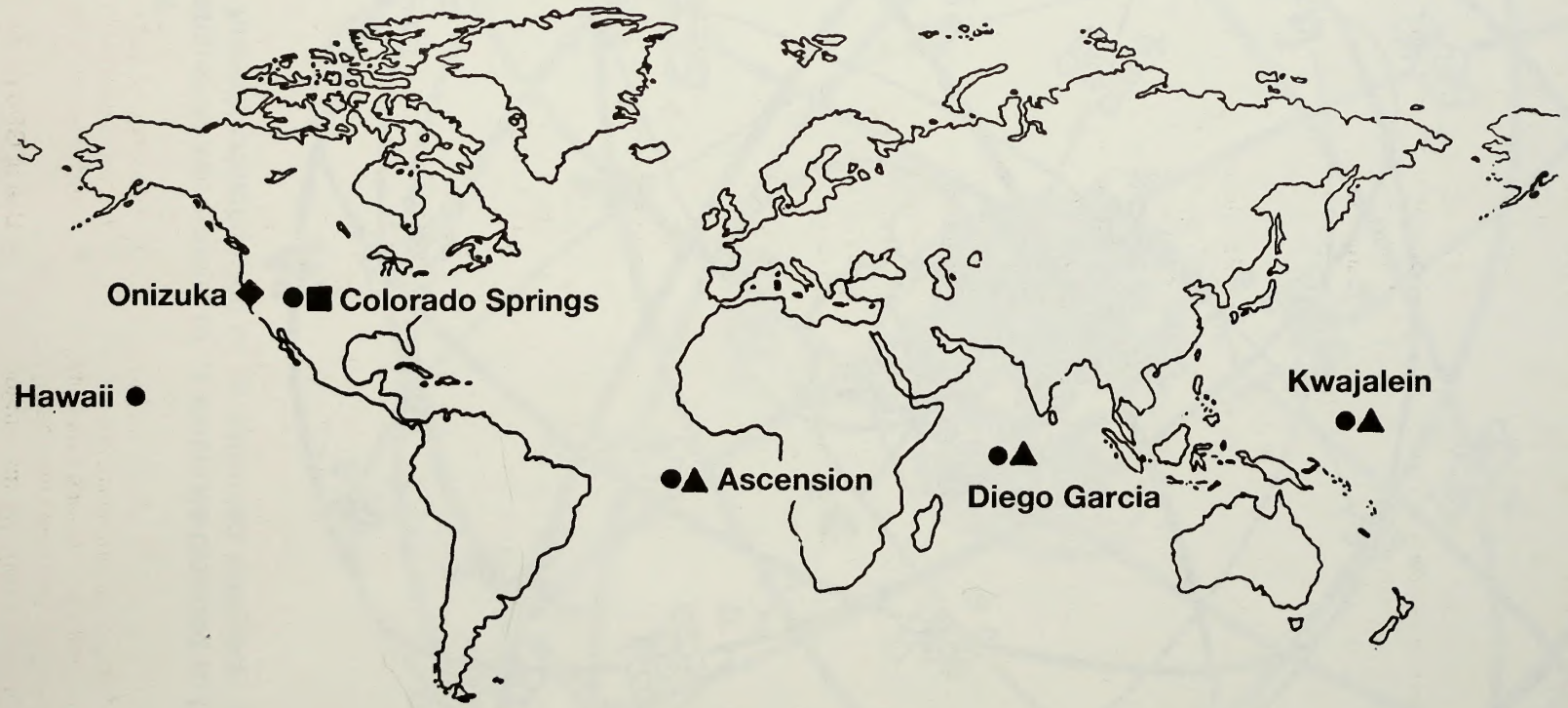


Figure 4

GPS Operational Control System



measuring the time it takes the radio signal to be transmitted and then received by the GPS receiver, a microprocessor in the receiver calculates the longitude, latitude, and altitude. Longitude and latitude can be calculated by triangulating three satellites, while the addition of altitude requires a fourth satellite.

At present, with the constellation incomplete until 1993, the GPS provides virtual 24 hours worldwide two dimensional coverage. The anticipated full constellation of 21 active satellites and three spares, will provide full time worldwide three dimensional coverage.

The types of receivers available vary greatly in design, but most are about the size of a lap top computer. The units can be easily mounted in a truck, helicopter, all terrain vehicle, or carried in a backpack. Presently there are many manufacturers and approximately one hundred types of GPS receivers being marketed. However, the existing receivers can be grouped by function (navigation, survey, geodetic, or scientific) or by accuracy capability (low, medium or high).

Commercial developing systems space-based navigation and positioning systems fall into two broad categories: dependent and independent. The dependent systems require the user to obtain data from more than one source. The independent systems provide all necessary data from one source. Dependent systems include Diffstar, Geostar System II, International Maritime Satellite (INMARSAT) System, and Starfix. Independent systems include Geostar System III, and Starfind.

The accuracy of the GPS varies from much less than 1 meter to 100 meters. The variations depend on the number of satellites, the characteristics of the receiver(s), methodology, and the processing method used. More discussion on system accuracy is presented in other sections of this report.

There are few significant limitations to the GPS. While the constellation is incomplete (only 16 operational satellites), the "window of visibility" is restricted for the 3D coverage. However, every additional satellite increases the size, that is, time of the window. When the constellation is complete in 1993 and the system is fully usable, the window will be for 24 hours a day.

The usefulness of the GPS is also limited by obstructions of the sky by tall buildings in downtown centers, or deep canyons which would limit the receiver's capability of signal reception. Similarly, thick forests with heavy, wet foliage impede signal reception. A man made limitation is Selective Availability (SA), which is controlled by the Department of Defense (DOD). For security reasons, DOD is inducing an intentional degradation of the GPS signals and navigation messages. The effect of SA can alter point positioning up to 100 meters 95% of the time. However, by using different techniques this effect can be reduced to two to five meters.

The Soviet Union has a similar developing system known as GLONASS which stands for Global Orbiting Navigation Satellite System. Because the orbits are slightly different, a combined GPS/GLONASS receiver may have advantages in speed, accuracy, and coverage.

Extraterrestrial positioning using satellites has been used for over 30 years. Recent Satellite Positioning Technology (SPT) is increasingly being used by industry and has been used by the military when relatively accurate and rapid determination of geographic location of points is required.

Recent innovations in technology have increased BLM's interest and use especially with the production of cost effective systems. The majority of BLM interest in this satellite based technology has been in the Global Positioning System (GPS), but other developing technologies such as satellite communication can greatly expand the potential of SPT.

The first satellite positioning system was the U.S. Navy's Transit Doppler with the first satellite launched in 1961, becoming operational in 1964. The six Transit satellites use receivers that measure Doppler shift to calculate coordinates. While Transit was developed for off-shore navigation, applications have included the surveying of precise geographic coordinates which requires the receivers to record data for up to 48 hours. The BLM has used Doppler technology since 1972.

The BLM has participated in SPT innovation and application development for land and resource management activities. Some of the unique uses resource managers have explored include:

— Flight-following using LORAN/GPS and a communication satellite to track an aircraft's last known position. BLM has led the innovative use of this technology. (For more detail see Appendix A.)

— Application of survey quality GPS and the older Transit satellites to obtain precise geographic coordinates of our cadastral survey monuments.

— Use of GPS receivers to navigate to a predicted geographic coordinate, with results within 100 meters.

— Use of satellite bio-telemetry to track the locations of big game will greatly contribute to the identification of critical winter range with accuracies to 500 meters.

— Field measurement/mapping resource data to within 5 meter accuracy, twice the accuracy of a 7.5 minute topographic map.

FINDINGS

Analysis of Current Uses and Needs

Current and Future Uses

The Land Surveying industry has been testing and using Satellite Positioning Technologies (SPT) in all aspects of surveying. The BLM's Cadastral Survey has over 19 years experience in SPT using Doppler Positioning and for the last four years with GPS. These uses have been primarily for establishing geodetic control on new surveys performed and using this data to create the Geographic Coordinate Data Base (GCDB). Recently, some state office cadastral branches have been testing the applications of GPS for uses in performing all measurements on a cadastral survey. Successes were noted in reducing crew sizes and time, and increasing accuracies, but more testing will have to be completed.

For resource based applications (i.e. accuracies between 2 and 25 meters) the U.S. Forest Service has been very active in this area for the last two years. They are presently using the Trimble Pathfinder unit to map roads, identify deceased trees, and mapping fire boundaries. These applications have proved to be very successful for them. The Forest Service plans on more equipment purchases and training all resource personnel to use this technology. The BLM has evaluated the uses of GPS, but has limited access to equipment. In the BLM at this time there are less than 10 resource units available. Even with this limited access there are clearly many applications for GPS in the BLM. Some of the potential uses include mapping and identifying:

Back country trails,
Roads,
Recreational and rangeland improvements,
Oil and gas well sites,
Water wells,
Hazardous material sites,
Wetlands habitat,
Wildlife habitat,
Riparian areas,
Unauthorized use,
Illegal crops,
Corner remonumentation,
Fire fighting support,
Archeological sites, etc.

The applications mentioned above can be accomplished with existing technology. The results of our survey indicate that nearly all states have made some applications or tests of GPS in resource management applications other than cadastral survey. The survey also indicates that CA, CO, ID, NV, NM, WY, and OR have GPS units on hand within their states. The tests completed by the BLM so far have proven that although the initial outlay for equipment will be high the Bureau can realize an increase in work production of at least two, if not three times. (For more detail see Appendix B).

The system can be used in any weather, at night, without line of sight required, and needs only one person to operate. A continuous line of data can be recorded to trace a route by driving a road, or biking or hiking a trail.

The BLM's effort in the Land Information System (LIS) is in the early stages of development. Before the interim LIS is complete, the BLM needs to address the issue of how to update data in the system and merge LIS data bases correlated from separate sources. These problems may be alleviated with the use of the Global Positioning System. Technology is now available that would enable the BLM to update all resource management information into the LIS. GPS will greatly improve mapping of resource data and serve as an effective means to ground truth digitized data.

One of the greatest advantages of GPS for LIS applications is that the data is collected quickly, with known accuracy and "ground truthed" with a common reference system (latitude, longitude, and elevation). With GPS receivers the coordinates, time, and other attributes, information may be collected and then exported to an LIS data base with no manual digitizing or entry operation. With the availability of portable and laptop computers, the post processing, specialized analysis (eg for road design, polygon closure, etc.) and even entry into GIS applications can be done in the field. Since GPS provides a common reference system, which is the same as the Geographic Coordinate Data Base (GCDB), data from GPS sources and sources rectified with GPS will register with each other.

Applicability to BLM Programs and Mission

For an in-depth discussion of GPS technology and applications see Appendix C.

This discussion will describe three levels of GPS applications in terms of accuracy, cost, skills, equipment and specific mission applicability. For a summary refer to Figures 5 & 6.

Figure 5

Global Positioning Systems
A SimplifiedSummary of Application Types

Application Types	Accuracy * + or -	Procedure/Processing **	Equipment	Training	Cost ***
High Precision+	< 1 meter	Differential/Post Processed	Portable receiver, Base receiver and PC for processing	Expert Level	$15,000
Medium Precision+	1-10 meters	Differential/Post Processed or Differential/Real Time#	Portable receiver and PC Portable and base receiver	Expert	$10,000
Low Precision+	100 meters	Autonomous/Real Time#	Portable receiver	General Level	<$5,000

* Accuracy will vary depending on number of satellites, position of satellites, characteristics of receivers, and processing methodology.

** The need for post processing for improved accuracy is dependent in part on the status of Selective Availability.

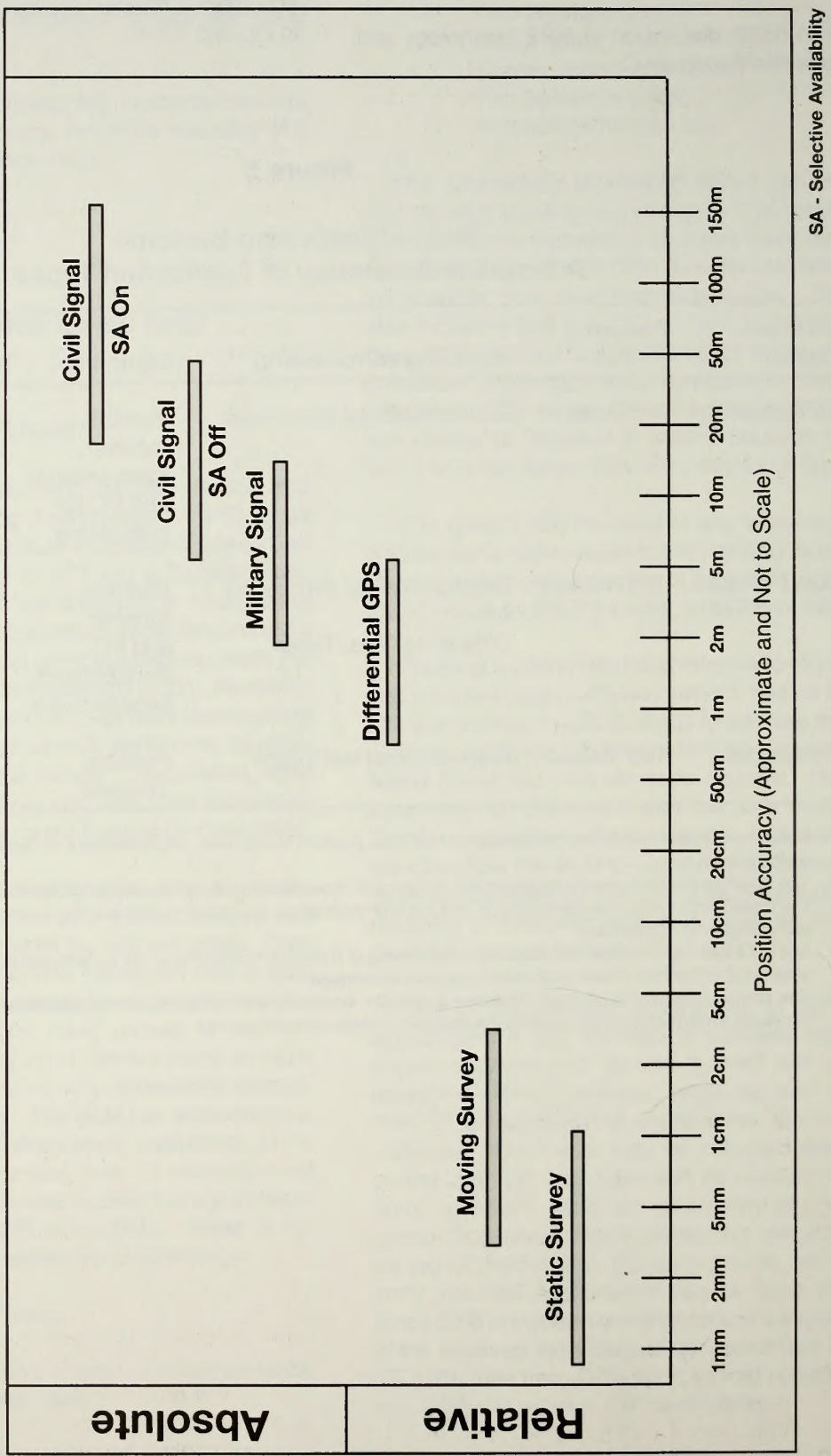
*** The costs shown are for equipment only and are high estimates. Equipment costs are decreasing rapidly with improved technology and competition.

\# Both of these methods can be adapted to positioning of a moving platform such as person walking, vehicle, aircraft, etc. by employing different software and communication techniques.

\+ The precision applies to all three dimensions, latitude, longitude, and elevation. Three satellites must be used for latitude/ longitude while four must be used by the receiver to determine elevation.

Figure 6

Levels of GPS Accuracy

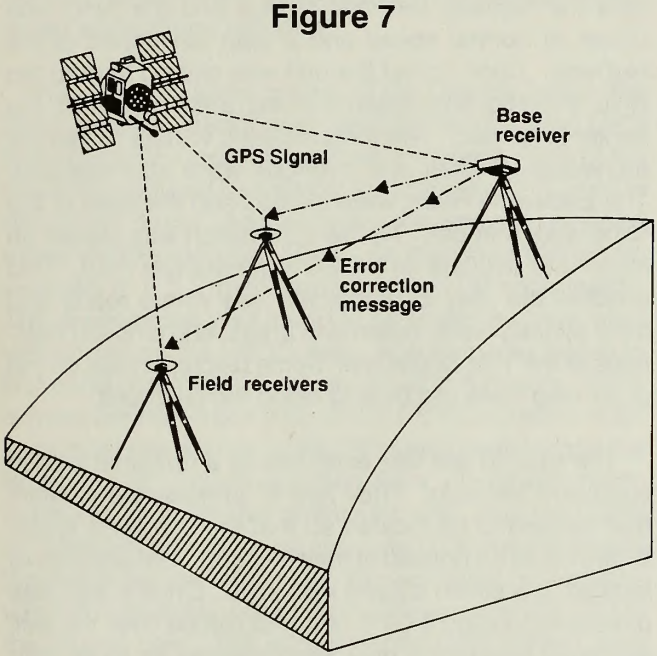


SATELLITE POSITIONING SYSTEM

High Precision Applications

The high precision type of application is essentially the geodetic or cadastral survey application of GPS which BLM has used for some time. It involves the most expensive and accurate receivers and is normally done on a project basis. A fixed receiver is stationed and is used in conjunction with a portable receiver, both of which receive signals from multiple satellites. The data is collected on site and then is post processed to achieve the desired level of precision. This technique can also be used to acquire real time location with similar accuracy if the fixed and portable receivers are connected via a radio communication link. (See Figure 7). The skill level required necessitates training of the crew at the expert level to prevent inaccuracies that may not be obvious. The following is a partial list of potential applications for the high precision application.

Figure 7



Office	Task or Type of Application
DO,SO	Determination of easement alignment and location,
RA,DO,SO	Drill hole location for water, gas, oil, coal, etc.
RA,DO,SO	Hazardous material location
DO,SO	Road construction survey
RA,DO	Timber sale boundary location
RA,DO,SO	Trespass or unauthorized use documentation
RA,DO	Wilderness area boundary location
RA,DO,SO	Photogrammetric control
RA,DO	Production verification

Medium Precision Applications

The medium precision procedure generally requires less expensive equipment but can be accomplished as well with the same equipment as above. Less time is required on site and the desired accuracy can be achieved with one portable receiver combined with post processing. If real time data is needed the differential technique must be used with a communication link between the fixed and portable receivers. Training to conduct this procedure will also be at the expert level due to the need for complicated post processing or the use of two receivers. Medium precision applications can be conducted on a project basis or a single site when equipment and skills are available. The following is a partial list of potential applications for this procedure.

Office	Task or Type of Application
RA,DO	BLM road and trail inventory or low impact right-of-way location
RA,DO	Fence line survey
RA,DO,SO	Cadastral corner reports (for existing corners and monuments)
RA	Compliance and enforcement work
RA,DO	Cultural site location
RA,DO	Drill pad location
RA,DO	Forest inventory plot location
RA,DO,SO	Incident/accident response and investigations
RA	Initial unauthorized use investigations
RA,DO,SO	Investigation of drainage
RA,DO,SO	Mining claim investigations
RA,DO	Monitoring site location
RA,DO	Rangeland improvement project location
RA,DO	Soil, vegetation or habitat mapping
RA,DO	Spring inventories
RA,DO	Stream inventory
RA,DO	Threatened and Endangered species inventory and monitoring
RA,DO	Timber sale layout
RA,DO	To complete "as built" and project completion reports
RA,DO	Wild horse and burro inventory or herd area location
RA,DO	Wilderness Study Area marking

Low Precision Applications

The low precision technique requires only one low cost receiver and the locations can be determined in real time with only a few minutes on the site. The training necessary for the user to conduct this procedure is general and the work can be conducted on a single site

at any time the required number of satellites are in view. As the number of satellites in the constellation increases and the technology of the receivers improves the accuracy of the procedure will improve. The potential uses for the low precision application is similar to that for medium precision application and will be determined for the specific case based on the need, equipment on hand, time allotted, and personnel/skills available. Currently, with DOD's SA implemented accuracies, of ± 100 meters 95% of the time, can be expected. The following is a partial list of potential applications for the low precision application;

Office	Task or Type of Application
RA,DO	BLM Road and trail inventory or low impact right-of-way location
RA,DO	Compliance and enforcement work
RA,DO	Cultural site location
RA,DO	Drill pad location
RA	Forest inventory plot location
RA,DO,SO	Incident/accident response and investigations
RA,DO	Initial unauthorized use investigations
RA,DO	Investigation of drainage
RA,DO	Monitoring site location
RA,DO	Rangeland improvement project location
RA,DO	Recreation inventory
RA,DO	Safety related monitoring of field personnel via radio
RA,DO	Soil, vegetation or habitat mapping
RA,DO	Spring inventories
RA,DO	Stream inventory
RA,DO	Threatened and Endangered species inventory and monitoring
RA,DO	Timber sale layout
RA	User visitor contacts
RA,DO	Wild horse and burro inventory or herd area location

Low precison techniques could be similar to medium precision techniques, but depending on the application, they may be different.

Because the locations derived from GPS can be directly input to any GIS system the improvement in both accuracy and productivity is even greater. The location of any of the above items can then be analyzed in combination with any other stored spatial data. (For more detail see Appendix D).

Because the equipment can be used in an aircraft (fixed wing or helicopter) the ability to accurately locate any of the above examples from the air further expands the utility and savings. Anyone who has attempted to plot a ground location from a moving aircraft in turbulent air can certainly appreciate this application.

Recent Field Tests for Resource Applications

Colorado State Office Efforts

Recently three tests were performed to evaluate the uses of GPS for resource management and its applications to the BLM. The tests were completed using one resource grade unit without selective availability enabled.

The first test was executed at the BLM's Anasazi Heritage Center (AHC) in Cortez, Colorado. The center's management desired an accurate map of the location of the center, the highway from Cortez to the AHC, the trails at the AHC, and the Escalante Ruins, an archeological site at AHC. The GPS unit was placed in a vehicle with the antenna mounted on the roof. As the unit collected data the highway between Cortez and the AHC was driven at normal speed and a map developed of the highway. Upon arrival the unit was carried to map the AHC building and determine the area on which the center is located. The trails allowing visitors to see the archeological sites and overlook were also mapped. The Escalante Ruins were located and the walls of the ruins were mapped. All this information was plotted on mylar and overlaid on a USGS quadrangle map. This enabled the user to graphically see where roads and trails actually were, determine areas, and pinpoint locations at the 1:24,000 scale. Some discrepancies on the quad map were discovered using the GPS unit.

The second test was executed for a resource area in southern Colorado. They had 47 artesian water wells that needed to be located so that the Colorado Water Board could be notified of their location. The wells were located in a seven square mile area. Once a well was physically located a GPS unit was placed over the well and point positioning data was collected for three minutes. Individual files were established in the GPS unit for each well. After all the wells were occupied a composite plot of all the wells was completed on mylar and overlaid on a quad map. The 47 wells were located and overlays completed in 12 hours. A savings of at least 5 times was realized over conventional methods.

The third test was completed for the law enforcement branch in Colorado. In this case, a private landowner had done some unauthorized road construction on BLM land. The investigators needed to determine the extent of the trespass. While driving on the newly constructed roads, a GPS unit was placed in a vehicle and approximately 6 miles of road data was collected. Cadastral survey monuments were located, data collected and the approximate limits of ownership was determined. The

mapped roads and cadastral corners were then plotted at a 1:24,000 scale and overlaid on a quad map. The mapping of these roads took a total of four hours to complete. Conventional methods would have taken 6 days.

These tests required only low accuracy data, ten to twenty-five meters was sufficient. If a second unit was used and placed on a known point accuracies could have been improved significantly to the sub-five meter range.

Wyoming GPS Operational Development Examples

The Wyoming State Office has performed several successful operational tests of GPS derived positions for the cultural, mineral, wilderness, range, engineering, and fire management programs in 1990. These operational applications included:

Historic sites and a portion of the Oregon Trail in the Rock Springs District were field digitized testing GPS technology to support the cultural program. Parts of the trail were mapped by walking the trail with GPS used in differential mode. Access to the site was also mapped using vehicle mounted GPS. All data was plotted on overlays to a 7.5' map using metric UTM coordinates. The access road was found to be realigned from what was shown on the USGS map. Accuracy was tested to first order control and found to be within 5 meters, which is twice the stated accuracy of the 7.5' topographic map. At another site survey quality GPS was used to map the landnet and provide supplemental photogrammetric control to an extensive prehistoric site. Adjusted GPS coordinates provided very accurate UTM coordinates to the archeological base map. Conventional ground survey ties to geodetic control would have added $5,000 to the project cost. The supplemental GPS control, also allowed for evaluation of the ground control survey's accuracy and assisted in providing a highly accurate product for the entire project.

Wyoming demonstrated cost effective use of GPS to support the fire management program. An active forest fire was mapped by GPS and the field crews were given a plot of the fire on a topographic map the same day. The GPS was also mounted in a helicopter and used to map a large prescribed burn and a year old forest fire in the Pinedale Resource Area. The results were plotted on a topographic map and appeared to be within the 7.5' mapping accuracy of ±40 feet. Helicopter GPS mapping of a fire proved very beneficial as the aerial view provided a better interpretation of the burned areas, removed very difficult access problems in rough topography, and allowed for quick mapping. Drawbacks included the high cost of helicopter time, though we estimated that some mountain fires would take weeks to map on the ground verses a few hours in the air with GPS.

Proposed Wilderness Area surveying and mapping provides unique ground positioning problems. In the Rock Springs District one area has mapped boundaries that do not coincide with ground identifiable features or cadastral survey monuments. The proposed boundary was an irregular line on a map. Coordinates were obtained from the map for 11 points along the boundary and transformed to the GPS datum (WGS 84) coordinates. These coordinates were used to navigate by helicopter mounted GPS to within an estimated 60 to 100 feet (SA off) of the predicted sites in a sand dune area. A temporary sign and site marker were placed at these sites along this boundary. Differential coordinates within 2 to 5 meters were collected for the boundary site and post-processed using control coordinates obtained from a NGS survey marker 20 air miles away. This procedure can help prevent future encroachment into the area by nearby oil and gas development. This GPS application solved a difficult problem identified by the DO engineering staff.

New oil and gas well drill pads and their support roads were mapped in the Sweetwater Desert. One well and it's support road could be mapped in about 30 minutes using differential GPS methods in this large gas field. Current maps were over 20 years old. GPS proved to be an excellent map updating tool. Large fields with extensive change and many non-accessible pipelines should use photogrammetry to initially map the field and GPS to maintain/update field development activities.

Detailed Application Examples

Unauthorized Use Investigations and Documentation

The first step in this example is normally the suspicion that some use has taken place on public land that is not authorized. Often this use occurs near a boundary or change in ownership or status, eg. public/private boundary or withdrawal. As part of the initial report of trespass, the location of the use can be documented using a low precision GPS procedure and the determined accuracy can be compared to the distance from the boundary. For example, the cabin or road is found to be (using GPS) 150 meters inside the public land boundary using a

procedure with an accuracy of ± 50 meters. This would be sufficient to proceed with the trespass action. If the use was determined to be 50 meters from the boundary a higher precision procedure would be required. For example, by post processing the recorded field data or by using a differential technique by first recording the GPS location of a known monument which, could be several miles distant, a higher precision procedure could be achieved.

Depending on the values involved the procedure can be extended to the high precision technique if appropriate. This approach can save 50% to 99% of the cost of a complete survey depending on the circumstances. Many receivers indicate the accuracy of the computed location and combined with appropriate training the user will be able to apply these values and other factors to derive the actual precision. GPS could also be used to determine acreage or length of the activity at any desired level of accuracy, depending on the values involved and the use of the results.

Monitoring Sites

The BLM does a variety of monitoring activities including vegetation photo plots, soil/vegetation transects, water quality, wells, precipitation, revegetation, and many others. One of the most time consuming tasks associated with all monitoring activities is the initial location of the desired site and finding the established site for repeated sampling.

One example of applying GPS to an existing technique is in the case of permanent range and wildlife study plots or transects. There are probably over 100,000 of such locations on land administered by BLM. These locations are recorded on a map in the studies file with an accompanying description. The field location is often marked with a post, which is often knocked down or removed. When the site is established (or by plotting from the map), the location, in latitude and longitude, can be recorded using GPS by usually applying one of the medium or low precision procedures, depending on terrain and vegetation cover. Recording the location in the file will allow the site to be more accurately plotted and more rapidly located for repeated samples.

GPS could be applied with an improved technique to enhance the BLM's ability to collect all of the monitoring data needed. Using existing maps or GIS data, the specialist selects target locations for monitoring. Using a helicopter equipped with both GPS and a camera, the desired locations are visited, adjusted as needed, and photographed, at any prescribed scale and height, recording the GPS location. These sites could then be rephotographed at any time by a contractor who could fly to and photograph 20 to 50 locations in a day, compared to 2-5 sites by ground transportation. The specialist then reads, compares, interprets and analyzes the photographs. If the photos indicate any changes of interest, the specialist can do follow-up field work as needed and visit only those sites where further on-site sampling is needed. The potential for more accurate, timely, and cost effective monitoring or compliance work is substantial. The technique could be tailored to a variety of monitoring needs from many program areas including lands, hazmat, riparian, range, fire, wildlife, forestry, T/E species, land treatment, mine rehabilitation, cultural sites, maintenance of water developments, even livestock or big game counts.

Road and Trail Location or Layout

The BLM conducts several activities which deal with locating roads and trails. Examples of these activities are laying out the location for minor construction of a road or trail, documenting the location of an existing road or trail, inventorying roads and trails for condition and/or maintenance, surveying roads for design and major construction, and surveying roads and trails for easement acquisition.

As an example, we can describe how to inventory an unsurfaced or primitive road for condition, realignment, and maintenance. The road can be traversed by vehicle or on foot while recording locations along the way using a GPS receiver. Due to the accuracy desired, the medium or high precision procedure would be used to achieve an accuracy of 0.5 to 10 meters depending on the terrain, type of maintenance, and values involved. The segments of the road needing specific maintenance prescriptions, eg., culvert cleaning, culvert installation, rolling dips, blading, etc., would be recorded from the receiver and either written or stored with the prescribed attributes. Staking and/or flagging may be done at the same time. If a section of the road needed realignment, several routes could be traversed and recorded for further analysis, eg., slope, length, environmental impacts, etc.

After completing the field work and recording the data, with only one employee required, the data could be entered or transferred into a PC for further analysis (to refine accuracy) and then used to compute the maintenance required in terms of stations, lengths, number of culverts, number of rolling dips, etc. If modifications are

needed the site can be revisited and the GPS used to relocate stations and make changes. Using GPS in this example reduces the crew time at least in half, creates data that can be uploaded into any computer application including GIS, and can be applied at whichever level of precision that is required.

Costs and Savings

There can be no doubt that GPS is a cost effective way of doing some of our work. The following table depicts the estimated number of units and costs to fully implement GPS in the BLM at this time. Costs for the equipment will no doubt go down in the future as competition and availability increases.

Office	Number	Number of Units	Equipment	Unit Cost/OM&R*	Training Cost	Total Cost Equipment and Training
Resource Area	140	140	Low Precision	$3,000	1 instructor 1 week $140,000	$560,000
District	58	116	Medium Precision	$10,000	1 instructor 2 weeks $116,000	$1,276,000
State Office	12	60	High Precision	$15,000	1 instructor 2 weeks $12,000	$912,000
Service Center	1	15	High Precision	$15,000	Already Completed	$225,000
BIFC	1	15	Medium Precision	$15,000	1 instructor 2 weeks $1,000	$151,000
Total	**212**	**346**				**$3,124,000**

* OM&R - Operation/Maintenance and Replacement
OM = These costs are estimated to average about $300/year/unit @ 346 units total OM costs = $103,800/year. Generally these units will last an average of seven years. The first year is under warranty.
R = These units last an estimated seven years or more; therefore replacement costs would be - $2,855,000 (total unit costs)/ 7 years = $407,857/year X 1.799* = $733,735
OM&R = Total annual costs = $103,800 + $733,735 = $837,535
* Water Resources current Federal Project Discount Rate = 8.75% (8/1/91)

The savings of field specialist's or technician's time in accurately determining their location for any type of work is estimated to be 25% to 70%. Assume the BLM has 3000 employees in the districts and resource areas who spend 25% or more of their time doing field work. If we could save just 5% of their time applying GPS technology the BLM would realize an annual savings of approximately $4,500,000, (1500 WM) based on a $3,000 WM cost. This time could be spent doing the AWP work or any of the important work which now is either postponed or left undone. While this is obviously a superficial and oversimplified benefit/cost analysis, it would amount to a ratio of over 5.4:1 annually over a seven year period (service life of equipment) excluding trainees salary costs during the training.

Based on the variety of effective uses, the relatively low cost of a phased equipment acquisition, the availability of training, the benefits of standardized location data, and the savings of time, the benefits of proceeding rather rapidly to implement this technology in BLM are significant. Moreover as equipment costs continue to decrease with better units, and annual work month costs continue to increase the BLM will realize even greater savings.

Feasibility of BLM Implementation

The entire NAVSTAR constellation will be deployed by 1993 which will provide essentially 24 hour a day three dimensional coverage. Based on the results of the numerous field trials and testing of this technology in recent years, both in cadastral survey and resource applications, the technology can be widely used in BLM for nearly all types of field work. Based on the results of the survey and the enthusiasm of those who have used the technology, there is a high level of interest and willingness to apply the technology among BLM employees.

The rough analysis of costs and benefits presented above reflects large potential savings and a high ratio of benefits to costs. What is lacking for general use of the GPS technology in BLM is the implementation of some limited structure, training and standards for specific program application. This could easily be accomplished over the next 2-3 years.

Cadastral survey staffs will be, at least initially, the most frequent users and have a consistently high skill level in the use of this technology. They should serve as the catalyst for BLM implementation. Resource program staffs should be involved as well as field users to ensure program standards and practical user needs are reflected. They can assist in the training and user support which will ensure a high level of quality control. Some standards for equipment, software, and procedures need to be developed over the next 12-18 months. The training and equipment purchase could begin as soon as the standards are completed. Equipment should be acquired over a 2-3 year period to allow for skills, technology, and procedures to evolve.

Analysis of Equipment

Equipment on Hand

Three types of Global Positioning System receivers exist in the BLM. They differ mainly by the accuracy each type acquires.

Survey accuracy GPS receivers can provide centimeter positioning. Navigation accuracy GPS receivers provide 100 meter positioning. Navigation accuracy can be improved to 2-5 meters with differential processing.

At this time, there are 23 survey quality GPS receivers in BLM. All 23 are in cadastral survey. Of the 23 survey quality GPS receivers, 17 are Motorola Golden Eagles, and six are Trimble 4000ST's.

There are approximately 16 navigation quality GPS receivers in the BLM. Cadastral survey has 8 of the navigation quality GPS receivers. The remainder are located in the district offices in Idaho and Oregon. Of the 16 navigational GPS receivers, 14 are Trimble Pathfinders, and two are Magellan Pro Nav 1000s.

Equipment Needs

Past experience with survey quality GPS receivers has shown that four receivers for each control project is sufficient. Cadastral survey has met its requirements for control positioning with fewer than 20 GPS receivers by sharing equipment.

It is estimated that cadastral survey will probably require 40 survey quality GPS receivers during the next two years, provided equipment is shared between the State Offices, and the Cadastral Equipment Cache provides a small stock of backup equipment. Engineering also has a need for photogrammetric control, road easement surveys and other engineering surveys.

There is a need in cadastral survey for high quality geodetic GPS receivers. These GPS receivers are characterized by their ability to acquire very high accuracies, sub-centimeter or better, and their ability to eliminate errors due to tropospheric and ionospheric refraction. A pool of these geodetic type receivers for loan will provide BLM with the best capabilities for the least money, and allow for the best maintenance and repair services.

Navigation quality GPS receivers would be used primarily in the resources area offices and district offices. There are approximately 140 resource and 60 district offices. Using navigation receivers to their fullest potential requires the use of more than one receiver at a time. This would place the R.O. and D.O. in need of 400-800 navigational GPS receivers. If this equipment is shared between the R.O. and D.O. these numbers should be lower.

Radio Flight Following

Introduction

SPT refers to the use of satellites for both calculations of positions on earth and communication of those coordinate locations to users. SPT activities include navigational satellites, satellite bio-telemetry, search and rescue satellites, and flight and vehicle following/monitoring systems. SPT includes two types of systems:

passive and active. Passive systems have a receiver that can calculate the user position. Active systems have a transceiver that can calculate coordinates and transmit the position to another ground location along with additional data.

In June 1988, the BLM began an evaluation of a new technology called Radio Determination Satellite Service (RDSS), with the goal of substantially improving aviation flight safety. That evaluation has proceeded rapidly and has produced unexpected results. Our evaluation and accompanying systems development have resulted in a viable, cost effective system which will provide a quantum improvement in flight safety. If the system only improved flight safety, it would be worth implementing; however, in the course of our work, we have discovered a multitude of spin-off applications which offer substantial benefits to line management; logistics management; wildlife surveys; law enforcement; cadastral survey; range, forest and wilderness management; hazardous materials transport; minerals management; firefighting; and emergency response. These applications offer unique opportunities to enhance mission accomplishment and save millions of dollars each year.

What is RDSS?

Radio Determination Satellite Service is a new commercial communications technology. It offers the individual user information on location that can be supplemented with two-way digital message communication. The service employs compact, portable radio terminals for mobile platforms and, eventually will offer miniaturized hand-held terminals for personal use. Each user is identified by and can be addressed through a unique identification code, similar to a telephone number. Every message sent or received over the network includes this code, and only the addressee can receive it.

Simply stated, RDSS determines the position of mobile transmitters attached to vehicles or man carried, and transmits that information to satellites. The information is downlinked to a master earth station and presented to the customer for display on CRTs which show a map and the position of the mobile unit. The information is presented in near real time and with a high degree of accuracy. On March 11, 1988, the Geostar Corporation put its first satellite into geosynchronous Earth orbit and the technology became reality.

Geostar Corporation holds all rights to RDSS and is the only company licensed by the Federal Communications Commission to provide RDS service. Geostar has licensed only three manufacturers to produce mobile systems for the use of the service.

Situation

Flight following is the knowledge of an aircraft position and operational status at any given moment. In its most elementary function, flight following provides life assurance to the occupants of an aircraft in the event of mishap. To be truly effective, it must provide information in real time, function regardless where the aircraft flies, and it must not interfere with the mission or aircraft operation. Should an emergency occur, the system should report that emergency and provide information to effect the most direct rescue of the survivors.

Within DOI, each Bureau and Service is charged with developing and implementing a flight following system. Implementation has taken many forms ranging from reliance on a check-out/check-in procedure to active flight following using radio systems. Despite the fact that DOI has been flying natural resource missions since the 1930s, an adequate flight following system has never been put in place. In some instances, the FAA system is relied upon. That system, using check out/check in methods, is particularly inadequate. The FAA published data indicate that, on average, the survivors of an accident will not survive their injuries or exposure until search and rescue personnel arrive. Attempts to utilize better systems have not gained much except confusion, lack of coordination, and expense. For example, the BLM has invested millions of dollars and countless manhours in VHF radio systems for flight following. These radio base stations are placed in nearly all district offices, many area offices, many state offices and all dispatch centers. These base stations are supported by a myriad of mountain top repeater systems scattered throughout the western U.S. Regardless, the system offers less than 40% coverage of the areas in which BLM flies. For the most part, the people manning these radios have little or no training in the use of the systems and **virtually none** have training in handling an aircraft emergency. Where an aircraft flies across political boundaries, the handoff from one system to another has proven a dismal failure. Systems within other DOI agencies are similar. The simple conclusion is that DOI has no adequate flight following system.

The RDSS system is a viable and cost effective solution to the dilemmas of flight following and emergency response. The potential for saving lives and reducing human suffering has no price tag. Beyond those considerations, the system offers a myriad of mission enhancements and cost savings which would pay for itself many times over. In the conterminous 48 states, and Alaska, the system is ready for implementation. Our testing in Hawaii is incomplete. About one third of the data for Hawaii has been gathered to date.

Current Methods in Acquisition of Equipment

Current methods of GPS receiver acquisitions include competitive purchase, GSA schedule, and leasing. Competitive purchase require detailed RFP's; the acquisition cycle may take six months, and there is no guarantee of getting a particular brand of receiver; but, competitive purchases can reduce receiver prices, and once in place can simplify the purchasing.

Purchasing GPS receivers on GSA schedule can be easier than competitive purchase. It is a matter of knowing what is available on GSA schedule and knowing the schedule numbers. There can be some competition on GSA schedule. Leasing GPS equipment is possible but the expense is prohibitive and there is sometimes a limit on the availability. Leasing four receivers for one month usually equals the purchase price of one GPS receiver.

Current Training Situation

Training Complexities

Meeting the BLM's Global Positioning System (GPS) training needs will be a complex and challenging task. GPS is a technologically advanced system which requires knowledge in mathematics, physics, electronics, statistics, and geodesy. Computer skills are essential; without them GPS data collection, reduction, and analysis cannot be performed. In many cases, the necessary knowledge and skill requirements to successfully operate the GPS are not germane to many of BLM's traditional disciplines; surveying and mapping science are exceptions to this rule.

Historically, satellite positioning has been utilized by selected BLM personnel for the past fifteen years, mainly by geodesists within the cadastral survey program. The first system used was the Doppler; it was a costly, complex, and difficult system to operate and maintain. The Doppler receivers were limited in number, and capable of only a single purpose, either geodetic positioning or navigation. GPS receivers on the other hand, cost significantly less and are capable of a wide variety of mapping, surveying, and navigational applications.

GPS, like other satellite positioning systems, enables a user to determine time, latitude, longitude, and height. Furthermore, speed and direction can also be determined by making measurements at regular, timed intervals. Each of these components can be measured at different accuracy levels, from sub-millimeter to several hundred meters of accuracy.

Regardless of the application or accuracy requirements, the users of satellite positioning systems must all achieve a base level of knowledge to insure consistent, high quality results, in order to be effective in their jobs.

Availability of GPS Training

The only federal agencies known to offer GPS training are the BLM, National Geodetic Survey (NGS), and the Forest Service (FS). GPS training is limited in the BLM and confined almost totally to outside sources. The BLM course is offered in conjunction with the NGS through the BLM/NGS Memorandum of Agreement. This is an advanced course in geodetic survey applications. The course is two weeks in duration and costs $1,200. The FS offers a three day course in resource applications of GPS. This course is offered through an arrangement between the FS' Missoula Technology and Development Center and the University of Montana. The cost is $350.

GPS training courses are available from private companies specializing in GPS training, GPS equipment manufacturers, university extension programs, professional societies, and government agencies.

However, only one company offers an extensive collection of GPS training seminars. Its offerings range from the "Fundamentals of GPS" to "Software Development and Integration", while cost ranges between $300 and $1500 each.

GPS equipment manufacturers offer courses based mainly on the use and applications of their products. These courses generally are provided free of charge with an equipment purchase. Cost to the non-purchaser or general public ranges between $100 and $250.

Several colleges and universities offer courses in GPS through their continuing education centers. These courses are from one to four days in duration and cost between $50 and $800.

Many state professional land surveyor societies offer seminars in GPS training as either a separate training course or in conjunction with a conference or convention. The cost varies from a few dollars to several hundred dollars. In many cases, continuing education units are awarded for these classes.

Evaluation of Current GPS Training

The evaluation of current GPS training was made through interviews with several BLM and non-BLM individuals who have taken several of the GPS courses listed above. In general, those interviewed found all the courses to be beneficial, up to a point. Major concerns are as follows:

- Training offered by manufacturers were more of a "sales pitch" than an actual course in GPS applications. Topics in which a company's product performed well were covered in detail, while shortcomings were down played as unimportant.
- Courses are either too general or too advanced; they lack a general progression from basic concepts to the more advanced subject matter.
- The amount of material covered tends to overload the trainee; several short courses would be preferable.
- Most courses do not address specific applications of interest to BLM employees.

Current Level of Interagency Cooperation

Based on the survey, the BLM as well as several other natural resource agencies are in various stages of implementing the use of Satellite Positioning Technologies (SPT). These agencies include Bureau of Reclamation (BOR), FS, National Park Service (NPS), Agricultural Research Service (ARS), and the Geological Survey (GS). Most of the above mentioned agencies are using SPT for resource management. With the exception of GS they are using low to medium accuracy units. The FS has been actively involved in GPS for the past 2 1/2 years. Successful uses have been developed for all types of resource management activities. They have developed a training center in Missoula, Montana which allows FS employees and employees from other agencies to be trained on the uses and applications of GPS.

Other agencies which have been involved in various coordination efforts include Office of Aircraft Services (OAS), several state/county/local government agencies, Defense Mapping Agency (DMA), Department of Defense (DOD), National Oceanographic and Atmospheric Administration (NOAA), Federal Aviation Administration (FAA), and National Geodetic Survey (NGS).

The degree of coordination and cooperation varies from state to state. Several states have formally organized "GPS User Groups" while others have informal or periodic forms of coordination. At present there is no formal national level coordination group that includes all of the natural resource agencies which are current or potential users. It appears that one of the difficulties in effective coordination is in combining technical expertise with user and management representatives. Writing an MOA with a couple of these agencies (suggest FS and GS) is recommended so that a clear channel of information can be shared with them. There is no reason that the BLM should be testing applications if that test has already been tried somewhere else and the information is available. A better understanding of what the FS is doing at the Missoula Training Center and GS is doing with their highly accurate instruments will assist all agencies.

RECOMMENDATIONS

Acquisition Strategy

Implementation Needs

The benefits of GPS technology to resource programs have been demonstrated with many applications throughout the private and public sector. These benefits are both quantitative and qualitative as demonstrated with more accurate information gathered in a shorter time-frame. BLM has demonstrated the benefits in several program applications and has estimated many other benefits across all programs.

The Satellite Positioning Technology Team recommends that the BLM apply a bureauwide, multi-program strategy for the implementation of GPS technology. The goal is to provide all field offices and programs with minimum capability for low, medium and high precision output. To summarize the strategy, by FY94 each resource area office will be provided with one low precision, point positioning system, designed to be run autonomously in real time (a total of 140 units bureauwide). These receivers must have the capability for differential applications with a base station. Each district office will have two medium precision level systems designed to collect data for differential post-processing (a total of 116 units bureauwide). The state offices will each have five high precision units (a total of 60 units bureauwide). The Service Center will have 15 high precision systems, and BIFC will have 15 medium precision units. The estimated total cost for this equipment is $3.2 million. This configuration will provide all

programs with access to the equipment which will meet the requirements of their applications. (See chart under Costs and Savings section for description of equipment and proposed distribution.)

In addition to equipment, several specific requirements have been identified to supplement bureauwide comprehensive and efficient spatial positioning:

- Training: Identifying and providing the necessary training to assure knowledgeable and appropriate use of the equipment.
- Methods and Procedures Standards and Documentation: Developing and documenting standards for the appropriate use of GPS.
- Applications and LIS Integration Development: Identifying and implementing, software interfaces needed to link field collected position data to BLM LIS/GIS applications.

Existing Procurement Options

The BLM has two equipment contracts in various stages of the solicitation process. These contracts provide equipment for the high and medium ranges of GPS accuracy. One contract (Contract H) was awarded in May 1991, and provides for high surveying quality results. The contract was developed to meet cadastral survey program needs, and allows for the purchase of 43 systems, 20 pounds or less, and 43 systems, 8 pounds or less. The service Center has purchased 12 systems, 6 in each category, for the Cadastral Equipment Cache. Inquiries to state office cadastral chiefs and to the Forest Service have been made to determine their needs through this contract.

The second contract (Contract M) was scheduled to be awarded in July 1991. It will provide up to 50 medium level GPS receivers with an option to purchase an additional 350 receivers. This contract was developed jointly with the FS to meet the same type of resource program needs as identified and addressed in this paper. BLM and FS will be able to purchase a maximum of 400 receivers from this contract, of which approximately 34 have targeted for various BLM state and district offices.

GSA has also awarded contracts with several suppliers for high precision level GPS systems. Although the technical specifications for these systems is comparable to Contract H above, the BLM cost is half of that awarded through the GSA contract.

Implementation Plan/Procurement Strategy

The diversity of intended applications and the wide range of equipment capabilities require a procurement strategy which offers a variety of equipment options, and the flexibility to alter the level of purchases over a given length of time, or allow a phased implementation as the BLM becomes more proficient in the use.

One goal of the implementation plan is to assure minimum equipment levels in all BLM offices. The BLM needs to identify offices which have not already achieved the basic equipment configuration as defined above. The existing contracts (Contracts H and M) should be used to the fullest extent possible to further supplement the baseline equipment goals. At this stage, it is unclear what, if any, excess capability will be available through these contracts. It is possible that the existing contract for medium level receivers will meet a good portion of BLM's needs for resource applications.

Secondly, the BLM needs to increase the level of equipment options available through Contracts H and M. Two contracts with those same technical requirements need to be awarded with unit options sufficient to provide the target bureauwide coverage.

A third contract should also be developed to provide equipment for low precision applications. The Service Center Branch of Cadastral Survey, Development (SC-678) can provide the technical specifications for this level of equipment. We also recommend that this organization handle the technical aspects of any bureauwide procurement related to GPS technology.

Funding Strategy

A bureauwide, multi-disciplinary implementation strategy as suggested in this paper, assumes that the benefits of GPS technology are sufficiently diverse to enhance all resource programs in the BLM. Therefore, we recommend a base level funding approach in which all benefiting activities contribute a percentage of the estimated $2.9 million (for equipment only). FY92 should be targeted to begin acquiring equipment through our existing contracts, and to begin the procurement process for the additional contracts. Our target completion date for equipment procurement is the end of FY93.

Acquisition for Remaining Implementation Requirements

The level of training, development of standards, and applications development requirements will vary and grow with use of GPS systems. We recommend that initial equipment use training be implemented with the delivery of equipment. The cost for performing this training is approximately $270,000. This does not include the cost of developing and preparing the training. Consideration should be given to specifying this training as an equipment contract requirement.

The BLM Cadastral Survey Program has expended considerable resources in identifying and developing the capability to provide training and documentation in the use of GPS technology. These capabilities are being developed through interagency contacts, private sector contracts, and in-house training capability. While the focus has been for the survey program personnel, there is an awareness of the need for the development of applied methodologies and standards and guidance for users without survey backgrounds. This effort should provide the baseline, and could be expanded to handle bureauwide requirements when widespread implementation is imminent. The WO Division of Cadastral Survey should provide an assessment of the status of their GPS training efforts, its applicability for resource program GPS users, and an action plan for expanding its use (if feasible).

The development of methods and procedures standards and documentation needs to be developed in concert with the training program and with input from the application specialists. This step should not be underestimated in terms of importance to successful implementation. Ensuring the appropriate use of the equipment is critical to understanding its value to our resource programs. Assignments should be made to each state with experience in specific program applications to develop methods and procedures documentation.

The ability to collect accurate position data in a relatively short time is an important advancement in our ability to make management decisions based on spatial information. Equally important are the steps involved in integrating this information with other related data, or with appropriate attributes and meta-data. Current successful resource applications with GPS should be investigated to develop requirements for LIS/GIS system integration. The BLM data administrators and data base administrators should also be involved in the development of these requirements.

Establish Base Control Monumentation and Permanent Base Stations

In order to obtain the greatest accuracy and maximize the ease of differential field GPS use, control monumentation needs to be placed at our field office sites. This will allow for easy setup of differential GPS base stations. It currently takes up to 30% of project time to establish a temporary base station for differential GPS. The team recommends that this control monumentation be initially located at BLM district offices. As GPS technology in BLM matures, active base stations in each state will greatly improve the benefit/cost ratio. These stations can be at each district office or located centrally and made available to the user through existing or proposed telecommunication networks. These centrally located base stations have the potential to become active systems with real time differential GPS. Active base stations can be shared with other agencies (see section on Interagency Cooperation).

An important side issue to standard base stations is GPS data standards. If the BLM intends to maximize benefit/cost it must procure survey quality and resource mapping GPS receivers that are compatible with the base station. The GPS industry doesn't have an across industry standard for raw GPS data. One company's GPS receiver isn't necessarily compatible with another. If this isn't corrected in the near future it is recommended that BLM procure survey quality base stations and resource receivers that are compatible. This would allow all accuracy levels of GPS users to use the same base station and greatly reduce training and system maintenance costs.

Radio Flight Following

The BLM has a critical need for Automatic Dependent Surveillance of mission aircraft. The need was identified and documented in a detailed study by the National Flight Following Task Force. Automatic Dependent Surveillance will provide a fail safe flight following system which is highly automated and which gives real time status and location of the aircraft in flight. Studies and field experience proved that the only system capable of providing 100% geographic coverage of the areas in which we fly, had to be satellite based. In June 1988, the BLM Aviation Systems Office installed the world's first Radio Determination Satellite Service (RDSS) system in

an aircraft. This satellite based system was a new technology using satellites in geosynchronous orbit as relays for small, light weight mobile transmitters to a hub. RDSS was selected as the system of choice for several reasons including the inherent design feature of automatic reporting of positions without operator interface. Proof of concept testing was conducted from June through December 1988. The results were so successful that BLM decided to undertake a full operational test involving a consortium of 12 government agencies and industry. The operational evaluation proved the extent of geographic coverage and reliability of the system necessary to flight following of BLM aircraft.

The original RDSS equipment used LORAN as the location driver. The system was acceptable for most areas but experienced data dropouts and position errors in the weak areas of LORAN coverage. BLM identified GPS as the preferable location driver and a prototype system was built and installed in a cooperator aircraft. This system proved the viability of GPS to drive the RDSS transmitter. Locationing and throughput were flawless throughout North and Central America.

BLM composed plans and funding strategies for full implementation of RDSS as the standard for flight following. All fleet and contract aircraft were to be equipped by 1993, and all others by 1995.

Geostar Corporation, the inventor and sole source of RDSS, failed as a business and filed for Chapter 7 bankruptcy in May 1991. As of this writing, no successor company has acquired the Geostar assets although there appears to be strong interest from two major corporations.

BLM plans, in order of priority, to:

1. Pursue all reasonable avenues with the intention of having a fully operational, satellite based, flight following system as soon as possible.

2. Retain present RDSS equipment, installations and consoles for immediate use if RDSS is restored by a Geostar successor.

3. Retain our present cooperative relationships with several federal agencies in research, development and operational evaluation of new technology to be applied toward the fielding of mobile tracking systems.

4. Participate in future high-tech endeavors such as the NASA Advanced Communications Technology Satellite experiment with the goal of developing enhanced operational systems for field use.

5. Investigate the propriety of outside consultation services to obtain recommendations for adoption or adaptation of the best fit system for BLM RDSS requirements.

Location and Level of Support

Being a relative new program to the BLM the location and focal point should be at a higher level in the BLM organization to gain recognition and support. The program should be located at the state office level (probably in the Division of Operations since the use is most prevalent there now) and at the SC level for overall coordination and technical support.

Delegation to the respective district can be done as the program develops and is implemented at an operational level in the district. This determination can be made upon further evaluation and assessment.

A master plan (i.e. a dynamic 5 year plan) should be developed at the SO level to identify use, development, procurement funding needs, other operational and administrative needs, and plans for the program.

An information and education effort should be initiated to inform the various activities of the facets of the technology and allow activities to innovate development and uses of the system. The system has use (but at various levels) for virtually all field activities (i.e. range, wildlife, forestry, recreation and wilderness, cultural, lands and realty, etc.).

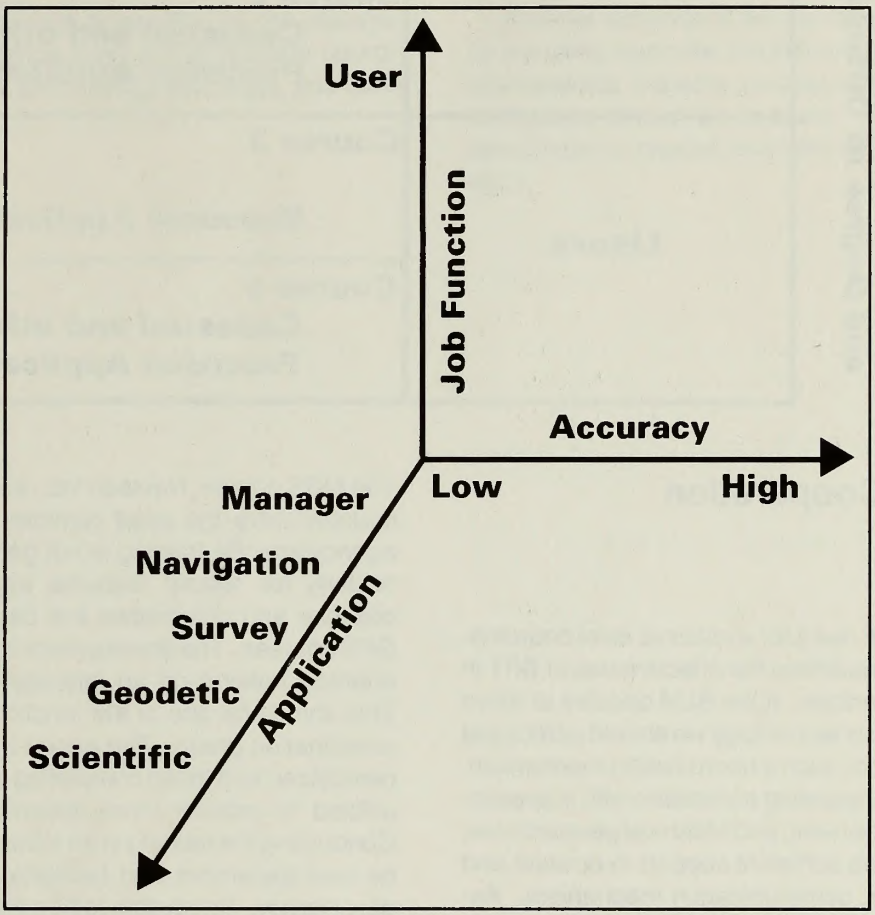
A workshop/training course should be developed and a technical team would be useful to function as a source to work with states, on a request basis, with users/potential users to help develop an understanding of the technology. The level of implementation is not predetermined but identified and developed through the above efforts.

Training

Identifying BLM GPS Users

The GPS user can be classified by using three criteria; application requirements, accuracy requirements, and job function. Application requirements refer to the type of work being performed; navigation, survey, geodetic, or scientific. Accuracy requirements refer to

quality of work which must be met, i.e. first order, 1:5,000, etc. Job function refers to who is using GPS and at what level within the organizational structure. For example, a user could be a manager scheduling work assignments or purchasing equipment, a field technician collecting data, or a cartographer using the data in a GIS. Together these classification criteria form a three dimensional matrix as shown in Figure 8 (below).



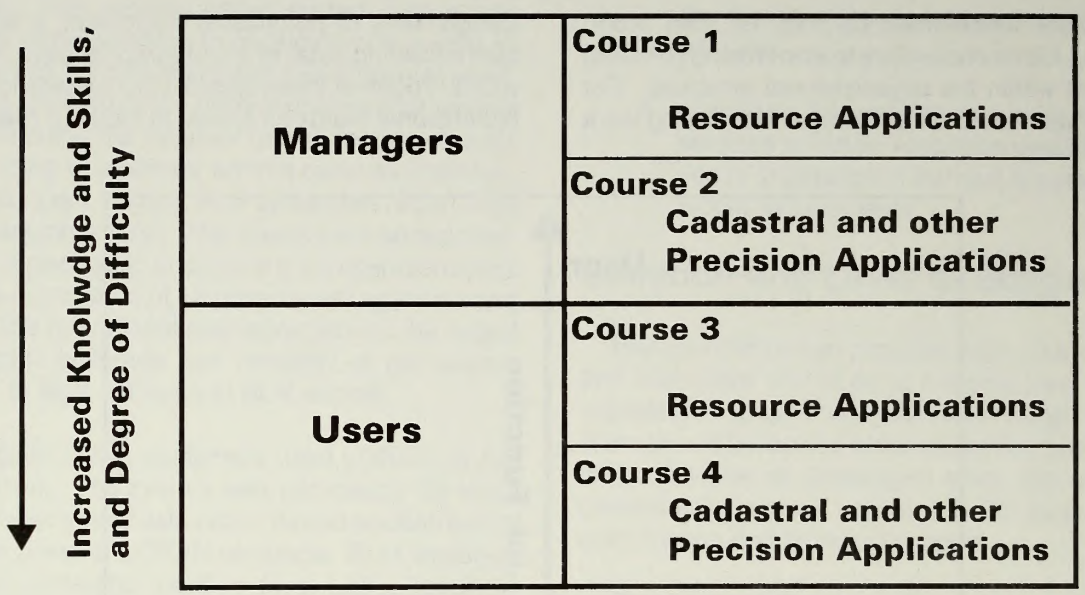
The amount of knowledge and skills necessary to insure consistent, high quality results, increases outwardly along each of the three axes. For example, the knowledge and skill level of a surveyor conducting accurate, scientific research should be greater than those of a manager, supervising a low accuracy, navigation application.

GPS Course Content

All potential GPS users will need to develop fundamental knowledge in mathematics, statistics, physics, electronics, and geodesy, and skills in the operating of GPS equipment and computers. The use of computers in the operation of GPS is essential and must be a prerequisite to any GPS training. Computers are used in every aspect of GPS work, from the initial mission planning phase to the reduction, analysis, and presentation of the data.

The Branch of Cadastral Survey Development (SC-678) has developed a general course outline (Appendix E) detailing all subject matter that should be presented as part of any GPS training program. For the most part, this outline is a model for any introductory course and the subject matter can be presented in detail to the student or can be briefly mentioned depending on user needs. Advanced courses have not been identified at this time, but it is anticipated that the advanced courses will emphasize methodology, network adjustments, and data sharing and integration.

Figure 9 (page 24) is a blueprint of proposed GPS courses.



Interagency Cooperation

General

There is a general need for a national level coordination mechanism to maximize the effective use of SPT in natural resource agencies. If the BLM decides to move ahead in the use of this technology we should participate in the establishment of such a coordination mechanism. It should consist of a standing committee with representation of user, management, and technical perspectives. The committee needs sufficient support to operate and an effective, regular, communication mechanism. Associating this committee with the Federal Geographic Data Committee (FGDC) might have some benefits and would be appropriate.

The national level group should address national/agency strategies, data standards, data exchange, agency leads for specific projects, budget, user requirements, coordination with other non-natural resource agencies.

Interagency groups should be established, or accomplished by existing interagency groups, as needed at the state/regional level to deal with site specific coordination issues. These issues would include coordinated data collection, equipment sharing, site/facility installation and maintenance, training, and technical support.

Training

The survey indicates that nearly all of the training comes from outside the natural resources agencies. The NGS course, Navtech Inc., and equipment supplier courses were the most common sources. Resource agency specific training is not generally available, particularly for natural resource applications, but some colleges and universities are beginning to offer SPT/GPS courses. The development of both expert and user oriented training on an interagency basis is needed. This should be one of the functions of the interagency coordination group. The expert training could be more centralized and those completing that training should be utilized to provide more decentralized user training. Conducting the training in an interagency framework will be less expensive and facilitate procedural and data consistency. Being able to fill a class at a field site near several agencies' field offices would save travel time and funds. General interagency coordination would also be achieved with this approach.

The BLM, FS, and NGS have held discussions, exploring ways in which GPS training courses can be presented in each agency without duplicating efforts. Each agency is examining its resources to determine how it can best contribute.

Data and Equipment Acquisition, Data Maintenance, Area Nets

Data acquisition should generally be coordinated at the data collection level. Some types of data collection should be planned at the state/regional level and even the national level to take advantage of efficiencies of scale and ensure cross boundary/jurisdiction consistency. If data standards are sufficient even attributes of many types of data can be consistent between agen-

cies. This is within the scope of the FGDC and Interior Geographic Data Committee (IGDC). It would seem that savings could be achieved even in data processing and storage if sufficient planning takes place to allow shared or lead agency arrangements.

Coordinated equipment acquisition at the state/regional level or field office level would facilitate coordinated data collection, processing, exchange, and even training.

The establishment of base station receivers (permanent or mobile) must be coordinated to achieve each agency's required coverage and precision. This coordination will need to take place at the national, state/regional, and local level and involve all users.

The maintenance of data is most appropriately done by the using agencies but in many instances when data maintenance impacts several agencies a system of notification should be in place. This applies to data about base or master receivers and processing parameters.

GLOSSARY

Absolute — Position or location determined entirely from the satellite signals with a single receiver unit.

C/A Code — The (Coarse/Acquisition) GPS or "civilian" Code.

Channel — A channel of a GPS receiver consists of a radio frequency and digital hardware, and the software, required to track the signal from one GPS satellite of one of the two GPS carrier frequencies.

Constellation —Referring to all of the NAVSTAR satellites in orbit at a given time, the planned level is 21 satellites with three orbiting spares, providing three dimensional coverage 24 hours a day.

Relative positioning — The determination of relative positions between two or more receivers which are simultaneously tracking the same radio positioning signals.

Dilution of Precision (DOP) — Is a measure of the geometric strength of the GPS satellite configuration.

GPS — Global positioning system refers to the system which uses the NAVSTAR satellite constellation operated by the U.S. Department of Defense.

L- Band — A group of radio frequencies extending from 390 MHz to 1550 MHz. GPS carrier frequencies of 1227.6 MHz and 1575.42 MHz are within this frequency width.

Multi-Channel Receiver — A receiver that can simultaneously track more than one satellite at a time.

P-Code — Precise or protected code. A dual frequency limited access code which can provide the most accurate positioning possible.

Post processing — Processing of satellite data collected by individual receivers to obtain latitude, longitude and height.

Real time — To achieve the desired result (latitude, longitude, and height) while tracking satellite signals.

Selective Availability — Deliberate degradation of the satellite signal.

Static Positioning — Positioning from a receiver fixed in one place.

APPENDIX A

SATELLITE POSITIONING TECHNOLOGIES RADIO DETERMINATION SATELLITE SERVICE

Introduction

In June, 1988, the Bureau of Land Management began an evaluation of a new technology, Radio Determination Satellite Service (RDSS), with the goal of substantially improving aviation flight safety. That evaluation has proceeded rapidly and has produced unexpected results. Today, we are able to state that our evaluation and accompanying systems development have resulted in a viable, cost effective system which will provide a quantum improvement in flight safety. If the system only improved flight safety, it would be worth implementing; however, in the course of our work, we have discovered a multitude of spin-off applications which offer substantial benefits to line management; logistics management; wildlife surveys; law enforcement; cadastral survey; range, forest and wilderness management; hazardous materials transport; minerals management; firefighting; and emergency response. These applications offer unique opportunities to enhance mission accomplishment and save millions of dollars each year.

This report is a summary of the RDSS technology, its capabilities and limitations, the BLM effort, and a plan for futuring.

What is RDSS?

Radio Determination Satellite Service is a new commercial communications technology. It offers the individual user information on location that can be supplemented with two-way digital message communication. The service employs compact, portable radio terminals for mobile platforms and, eventually will offer miniaturized hand-held terminals for personal use. Each user is identified by and can be addressed through a unique identification code, similar to a telephone number. Every message sent or received over the network includes this code, and only the addressee can receive it.[1]

Simply stated, RDSS determines the position of mobile transmitters attached to vehicles or man carried, and transmits that information to satellites. The information is downlinked to a master earth station and presented to the customer for display on CRTs which show a map and the position of the mobile unit. The information is presented in near real time and with a high degree of accuracy. On March 11, 1988, the Geostar Corporation put its first satellite into geosynchronous Earth orbit and the technology became reality.

Geostar Corporation holds all rights to RDSS and is the only company licensed by the Federal Communications Commission to provide RDS service. Geostar has licensed only three manufacturers to produce mobile systems for the use of the service.

Background

Natural resources aviation activities are, by necessity, conducted in close proximity to the earth's surface. They are conducted in relatively unpopulated areas and often out of sight or communication with any other person. DOI flight activity spans more than 100,000 flight hours each year - the equivalent of a large airline. We accomplish that flying using a fleet of 85 government owned aircraft and more than 2500 private sector aircraft contracted to DOI. BLM flight activity comprises about one third of the total.

Flying close to the surface puts an aircraft at higher risk than flight at altitude. In addition to the obvious danger of collision with wires, trees and, towers, a low flying aircraft is subject to sudden and invisible wind shear, mid-air collision with military jets, seriously reduced performance in high density altitude conditions and a remarkably high pilot workload. These dangers are well documented in our aircraft accident reports as the most frequent cause of accidents. Within the Department of Interior, we experience, on average, more than 14 aircraft accidents each year.

Invariably, one common factor characterizes these accidents: interminable delay between the mishap and the arrival of rescue personnel. This delay has resulted in documented fatalities, protracted injuries and needless human suffering. The cost associated with search

[1] Understanding Radio Determination Satellite Service, Geostar Corporation, March 1989.

activities, lost work time and civil settlements, directly attributable to this delay, is incalculable but clearly runs to several millions of dollars annually.

Situation

Flight following is the knowledge of an aircraft position and operational status at any given moment. In its most elementary function, flight following provides life assurance to the occupants of an aircraft in the event of mishap. To be truly effective, it must provide information in real time, function regardless where the aircraft flies, and it must not interfere with the mission or aircraft operation. Should an emergency occur, the system should report that emergency and provide information to effect the most direct rescue of the survivors.

Within DOI, each Bureau and Service is charged with developing and implementing a flight following system.[2] Implementation has taken many forms ranging from reliance on a check out/check in procedure to active flight following using radio systems. Despite the fact that DOI has been flying natural resource missions since the 1930's, we have never put an adequate flight following system in place. In some instances, we have relied on the FAA system. That system, using check out/check in methods, is particularly inadequate. The FAA published data indicate that, on average, the survivors of an accident will not survive their injuries or exposure until search and rescue personnel arrive. Our attempts to emplace better systems have not gained much except confusion, discoordination, and expense. For example, the BLM has invested millions of dollars and countless man-hours in VHF radio systems for flight following. These radio base stations are placed in nearly all District offices, many Area offices, many State offices and all Dispatch Centers. These base stations are supported by a myriad of mountain top repeater systems scattered throughout the western U.S. Regardless, the system offers less than 40% coverage of the areas in which BLM flies. For the most part, the people manning these radios have little or no training in the use of the systems and **virtually none** have training in handling an aircraft emergency. Where an aircraft flies across political boundaries, the handoff from one system to another has proven a dismal failure. Systems within other DOI agencies are similar. The simple conclusion is that DOI has no adequate flight following system.

Legalities

Flight following is a legal responsibility. By definition, a Flight Dispatcher (who conducts flight following) exercises responsibility with the Pilot-in-Command in the operational control of a flight. A Flight Dispatcher performing duties in air commerce is required to meet certain stringent prerequisites, complete appropriate training, have two years immediate similar experience, pass written and practical tests before receiving a Flight Dispatcher Certificate.[3] Only then may that person act in the capacity of Flight Dispatcher. DOI has taken a more casual approach to the job. In most places where we have personnel, hired to fill the flight dispatch function, the incumbents have no specific training, meet no particular standards, and are not tested nor certified for their positions. In many cases, flight dispatching is performed by secretaries or clerks who happened to be in the office and were assigned the duty collaterally with their primary function. Across the board, these people are singularly unprepared to cope with an aircraft emergency or to assist an aircraft in flight.

Standards

Departmental Manuals require a flight plan be filed for each flight. The **implication** therein is that some type of flight following will result. The premise is false and flight following usually does not take place. DOI does not impose flight following standards on the bureaus and agencies. Rather, a policy of laissez faire allows the individual agencies to develop their own standards, **if they so desire.** Only the Bureau of Land Management has published flight following standards.

Standards put in place the criteria for performance of the function. They are essential to establishing a system which will provide timely search and rescue. Without standards, any level of performance (or no performance) is acceptable; a situation which we have clearly shown to be inappropriate.

Standards for flight following must include criteria for accuracy and timeliness. Additionally, such standards must describe criteria for action should an aircraft become overdue or crash. Lastly, such standards should allow deviations, sanctioned by proper authority, when circumstances warrant. Lacking these standards, we

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[2] OAS Operational Procedures Memorandum (OPM) 89-13, March 1, 1989.

[3] Federal Aviation Administration, Federal Aviation Regulations Part 65, Subpart C - Aircraft Dispatchers.

experience substantial confusion when more than one agency is involved in dispatching, flight following, or controlling a flight. More often, no flight following takes place.

Methodologies

Flight following responsibility must rest with only one office at a time. Our experience with present attempts at flight following within BLM illustrate that segmented flight following responsibility does not work. We have more than 25 years of unfortunate history in trying to refine such system. It still does not work! The human element has been unable to agree upon and emplace a handoff system when an aircraft crosses political boundaries. In some circumstances, two or more offices are trying to flight follow the same aircraft at the same time. The result is no line of accountability, no one knows who is "in charge", and occasionally, everyone goes home while the aircraft is still flying because "someone else" is flight following. Given the lack of managerial direction, standards, training and understanding in the dispatchers, the failure is to be expected. The situation is exacerbated by the lack of adequate communications systems. If the human problems could be corrected, a system relying on VHF radio still could not function. Given the millions of dollars necessary to install additional radio systems and mountain top repeaters, and given the hundreds of FTE positions to operate them, there are not enough radio frequencies available to support that system.

Defining Alternatives

In November, 1987, BLM convened the National Flight Following Task Force. Under the Chairmanship of the Oregon Deputy State Director for Operations, the group was chartered to study and define the flight following situation, examine all supporting technologies existing and five years into the future, and to develop plans and recommendations for a viable system. The members comprised representatives from BLM, OAS and USGS. Participating, were subject matter experts in communications, aircraft management, logistics, aviation safety, pilots, and line managers. The resulting studies and report[4] concluded that only one known technology would support a truly effective flight following system - Radio Determination Satellite Service (RDSS).

Proof of Concept

On March 14, 1988, Jack Wilson, BLM Director of the Boise Interagency Fire Center, endorsed a limited Proof of Concept evaluation of RDSS in an aircraft. The test was to be managed by the office of the BLM National Aviation Safety Manager. Plans were immediately prepared and the acquisition process begun to obtain the hardware. Working to BLM's specifications, special antennas were developed for an aircraft application. The hardware shipset was delivered in early June 1988, and three days later, BLM had the world's first airborne RDSS system.

The manifold intent of the evaluation was to determine whether the system would work in an aircraft and if so, what were the effects of altitude, terrain masking, aircraft attitude and physical location (geographic coverage). The aircraft selected was a deHavilland DHC-6 Twin Otter belonging to DOI. We felt that this aircraft would give us the toughest possible test of the system because it is used to drop Smoke Jumpers throughout the Western U.S. It typically flies at extremely low altitudes, in canyons and forests, outside of any radio coverage and constantly maneuvers in tight turns and banks.

The Proof of Concept test continued for 7 months. During that time we gained a wealth of information about the technology and aviation applications. There were some frustrations, mostly having to do with our monitoring station which could not, at that time, give us real time information. Because of the software we were using, we had to dial into Geostar Central to get position updates and we were always at least 15 minutes behind the aircraft. There were some hardware problems but they were attributable to the power converter (Government supplied) which we were using in the aircraft.

Overall, the test results far exceeded our expectations. The technology performed flawlessly and we proved the feasibility of the airborne application.

OPERATIONAL EVALUATION

In November 1988, Lester Rosenkrance, the Associate State Director, Alaska BLM, learned of our efforts and successes with RDSS technology. Realizing the potential for improving aviation safety, especially in

[4] Report of the National Flight Following Task Force, BLM, 1988

Alaska which traditionally has had a severe problem with flight following, Mr. Rosenkrance offered to support a next phase evaluation which would include testing in Alaska. A test plan was prepared[5] and agreed with the participants. This was an unprogrammed requirement and no Annual Work Plan monies were available to support the effort. Consequently, it was decided that the evaluation would take place over a two year period using normal mission aircraft. Shipsets of hardware would be installed in a variety of aircraft which would then fly their normal mission profiles. Aircraft were selected based on their geographic ranging, mission altitudes and diversity of speeds. Several helicopters were also selected. We realized that we could have gathered the data in about six months instead of two years but we did not have the 4.6 million dollars we would have needed for dedicated research aircraft.

Using the $35,000 provided by Alaska BLM, we purchased the equipment necessary to set up a bare bones flight tracking station at BIFC. In order to get the necessary number of aircraft for the evaluation and to spread the cost of the aircraft shipsets, we negotiated agreements with a number of other agencies. In accordance with the test plan, each of these participants agreed to equip one or more of their aircraft with the system and allow us to track it. Simultaneously, we were working with the Department of Transportation, Transportation Systems Center, Advanced Concepts Division, (Hereinafter TSC) on a new form of mapping display for the system. We were also working with Geostar Corporation and their licensee Railstar Control Technology, Inc. to learn as much as possible about the technology before the evaluation began.

COOPERATING AGENCIES

The first agency outside of BLM to join in the effort was the U.S. Fish and Wildlife Service. The National Park Service contributed supporting funds, and we installed the second shipset in a FWS turbine Beaver DHC-2T, N-754, stationed in Juneau, Alaska. This aircraft offered some unique opportunities for geographic testing. It is flown in support of the waterfowl Flyways program and its missions range from southern Mexico to northern Alaska. We installed the system and the pilot departed immediately for Mexico to begin a winter waterfowl survey. At this time we were several months from getting the equipment for our own tracking station and so Railstar would produce printouts of the flight track each day and fax them to us for evaluation. TSC had a tracking station at this time and could print out the flight track of the aircraft on maps (Railstar could not print graphics.). TSC sent these flight tracks to us after each flight. As the aircraft crossed the Mexico border, our level of excitement began to climb. The system was not designed to work beyond the 48 States and we were pushing the edges of the envelope of knowledge. Two weeks after crossing into Mexico, the survey was completed and the aircraft crossed back into southern California. In those two weeks, we had tracked N-754, all over central and western Mexico. Our success was shared by the engineers and scientists at Geostar and Railstar. Over the next several days, we tracked the aircraft from California to Juneau. The system worked as advertised and we had our first flight track in Alaska, at that time, the northern most test of the system.

From that time, until now, we have enlisted eleven other Federal entities to join us in the endeavor and there are fifteen aircraft designated as evaluation systems. More than thirty aircraft are presently equipped with operational systems. Several ground vehicles and watercraft are also operational.

With the strong support of the BLM Director, BIFC, we established the Boise Flight Track Center to manage the operational evaluation of RDSS for flight tracking and to develop additional applications. Boise FTC went on-line in MAY 1989.

SUCCESSES

At the time of this report, we have 23 months of operational experience with the RDSS system. This is multiplied several times by the additional number of aircraft equipped with the system in the last 12 months. We set out to evaluate several parameters:

Limits of geographical coverage.

The RDSS system was designed by Geostar to provide service in the 48 States. Our testing and testing in other vehicles has proven the viability of the system from the Northern ice cap to 16 degrees South latitude (the Southern border of Venezuela) and from Hawaii to the coast of England. Summarily, everywhere that the

[5] Operational Evaluation Project Test Plan, BLM Aviation Safety Office, DEC, 1988.

Department of Interior flies in the Western hemisphere is covered by the satellite system. Until recently, the LORAN systems which provided the positioning information to the system did not provide 100% coverage of the U.S. The "mid-continent gap" is a well known phenomenon in aviation and refers to the lack of or weak coverage by LORAN in some parts of central North America. A LORAN system with high gain and rapid algorithm updates can overcome most or all of the drop out situation in those areas. This is the type of LORAN integral to the RDSS shipset. During our testing, we have seen LORAN dropouts in small areas of central New Mexico and northwestern Arizona. Within the past few months, the U.S. Coast Guard installed two new LORAN chains to cover the mid-continent gap. These new chains will also fill in the coverage of Mexico and Canada where many DOI missions are flown.[6] Our testing indicates that the mid continent gap is now effectively filled.

Accuracy

Geostar Corporation claims an accuracy of 1/10 mile for the system. Our testing indicates that this claim is very conservative. We have consistently achieved accuracies of 60 feet in latitude and longitude. These figures are consistent in the mid latitudes with the repeatability of LORAN accuracy and consistent with one second of latitude and longitude, which is reported by the system. Absolute accuracy is consistantly achieved within 1/10 mile.

Reliability

Tests for reliability have included those for the effects of weather, and effects of terrain masking, systems failures and their causes. The system has now been flown in all types of weather with no apparent effects. Terrain masking is a possibility if the aircraft is positioned such that the satellite transmit antenna is blocked from reaching one of the satellites by high, steep terrain. In the conterminous 48 states, we have not seen any terrain masking. Despite flying in canyons and "behind" mountains, the system continues to reach the satellites. In Alaska, the satellite look-down angle generally exceeds the system design parameters. Original calculations of antenna radiating patterns indicated that the system might not work well in Alaska. These estimates were based on the use of satellite #1 which is stationed at 87 degrees West longitude. After several months of experience flying four test aircraft in Alaska, we know that the system, where it has been tested, generally works well. We have seen terrain masking north of the Alaska Range when the helicopter flying there was very close to the base of the mountains and working below 500 feet altitude. In those circumstances, terrain does block transmission to the satellite at 87 degrees West. This area of terrain masking comprises less than 1% of the area tested in Alaska.

We have experienced two systems failures during testing. The first was in helicopter N86TA. This system was installed by the vendor company. During installation, the mechanic over torqued a bulkhead connection on the high power amplifier and destroyed continuity. Troubleshooting and repairs required nearly a week as the damage was hidden. During the Alaska field season, we experienced additional problems with this aircraft. Whether those problems are attributable to installation or operator error are as yet undetermined but are being investigated. The other aircraft to experience problems was Argosy N1430Z stationed in Fairbanks. Due to the wet summer in Alaska, the aircraft flew very little which made evaluation difficult. The root cause of the intermittent transmissions from this aircraft is suspected to be a bad coaxial antenna cable or poor antenna grounding. The cause is being investigated. Other than these instances, the system has worked very well in all installations.

Spurious Emissions

Installation of any electrical or electronic device in an aircraft requires that no spurious electromagnetic emissions from the device interfere with critical navigation, engine control, flight control, communication or systems monitoring equipment. Each aircraft installation of RDSS systems is ground checked prior to release for flight. Flight testing occurs during the subsequent several missions. We took an appropriately conservative approach to the use of the system during instrument flight conditions in order to assure that there was no chance of interference.[7] We have seen no spurious emissions effects in any aircraft and several aircraft have been approved to use the system in instrument conditions.

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[6] Report of status of NOCUS and SOCUS LORAN stations, extract, United States Coast Guard, 08/24/89.

[7] RDSS Project Test Plan, Spurious Emissions and Safety.

APPENDIX A

Helicopter Installations

Information leaving the aircraft antenna system does so in burst intervals. The actual data burst is nominally 12 milliseconds. The potential exists for the data burst to be completely or partially blocked by the overhead rotor blade passage of the helicopter main rotor system. Metal rotor blades (rather than fiberglass) posed the worst potential for interference. Rotor configurations (number of blades) raised questions of time lapse phasing and effects of blade disk density. As expected, we have seen occasional data drop-outs from metal rotor blade passage but they are very infrequent and non-consecutive. Our data show a negligible drop-out rate $\leq 4.3 \times 10^{5}$, or less than 2 per hour. This is well within the flight following standards of BLM.

Aircraft Attitude

Early in our evaluation we conducted bank angle tests to determine the effects of aircraft pitch and roll on satellite communication. The pilot flew the aircraft in sustained 60 degree bank angle turns through several revolutions in each direction. A Geostar project engineer aboard the aircraft monitored the test. Despite several minutes of turns in each direction, no data points were lost. Since the transmit radiation pattern is omnihemispherical, this test also served to evaluate aircraft pitch attitude. Theoretically, if the aircraft were banked away from all satellites at the instant of transmission, at an angle exceeding the satellite look-down angle, the transmission would be lost. That this does not happen, attests to the tolerances for antenna dB gain built into the system. These same tolerances also explain why the system works so well in Alaska where it was never designed to operate.

Aircraft Altitude

The shipset hardware we are using is certified by the manufacturer to an operating altitude of 10,000 feet msl. We have incrementally tested the system to 23,000 feet msl in an unpressurized aircraft with no degradation of performance. The system is being routinely flown at 41,000 feet in a pressurized aircraft with no degradation of performance.

Select System Features

The inherent design characteristics of RDSS offer some particularly attractive features for flight following and spin-off applications. The first of these is the security of the data transmissions and messages. Information is transmitted from the mobile unit (R/T) in a preformatted packet of 1024 bits (1 Kb). This packet contains the unique identifier of the transmitter, the location of the transmitter and any information in the message "box" of the data string. The base band processor in the R/T chops the 1024 bits into 130,000 "chips" and spreads these chips throughout the authorized frequency band. This spread spectrum technique assures that the data transmission is not interceptable nor interpretable. Only the algorithm in the Geostar Central master computer can reassemble the information. For real time users such as flight following, the information is delivered in encoded form on a secure, dedicated land line to Railstar. There it is sorted, formatted, analyzed and error corrected before being delivered to the customer via land line or V-SAT link. The information is still encoded until it reaches the customer's processing station. There, a unique security code in the customer console performs a handshake with the mainframe computers at Railstar. Only when the customer is properly identified, is the transfer of information allowed to proceed. Neither scanners, wiretaps or even theft of the software will permit an unauthorized individual access to your information.

Another feature of the system is the ability to send digital messages from the mobile unit to the console and back to the mobile unit. These messages are entered on a small hand held keyboard in the vehicle and transmitted by pressing the "SEND" button. They appear a few seconds later on the console data screen. Messages from the console are simply entered at the keyboard and appear on the display window of the vehicle keyboard. Using this feature to explain diversions for weather, change of flight plan while enroute, passenger status, vehicle status or to direct the pilot can save dollars, time and frustration.

Automatic Emergency Reporting.

Should the aircraft encounter an emergency and the pilot have sufficient time, he may activate a single button emergency switch in the cockpit. Instantly, an emergency message is sent from the aircraft to the console. At the Flight Track Center console an alarm sounds,, the icon of that aircraft turns red on the screen, the word "EMERGENCY" and the location of the aircraft is displayed on the data screen. This same action can be accomplished using the cockpit keyboard. This option offers the input of text to explain the emergency. If the aircraft crashes and the pilot has not had time to manually report using either of these keys, the system software will search for the next scheduled interval location

report from the aircraft. If the aircraft has not automatically reported its location within a preset interval, the system assumes the emergency and reports it on the console.

Data Port

The R/T unit has an RS232 interface port which allows the input of additional digitized data into the information string. Eight channels of information may be entered and these are transmitted along with the position information of the aircraft. Any type of data which can be digitized may be transmitted. Applications to date include position information from GPS and INS, altitude, airspeed, heading, engine oil pressure, and other vehicle health parameters.

LIMITATIONS AND CONCERNS

Use of continuous surveillance has raised questions of "Big Brotherism" in some circles. The concern may be well founded if the application of the technology were to be misused or abused. In aviation applications where the prime use of the system is to improve the safety and well being of the aircraft occupants, the initial feelings of doubt have always given way to the feelings of increased security. Flight crew response to the system has been overwhelmingly positive.

In order to assure that the technology is neither abused nor misused, the people responsible for flight following must be professionals with a vested interest in assuring the well being of the aircraft occupants. The only surety that the technology will actually perform the functions we are discussing, is to manage flight following with trained professionals who, by job description, assume these responsibilities and authority. Untrained, untested, non-certified, or collateral duty personnel cannot perform flight following or emergency response.

Obsolescence must be considered in the fielding of a new technology. Assuming a period of time to implement, will the technology be outdated by the time it is in place? The National Flight Following Task Force undertook to examine all emerging and promised technologies which had potential to support aviation needs. Their conclusion, and we confirm, is that there are no emergent sciences on the horizon which will supplant RDSS.

SPIN-OFF APPLICATIONS

The BLM Aviation Safety Office has made several contributions to the science which can be classed in two major groups: flight following and other natural resources applications. In flight following we have contributed 86 innovations which have improved the system for this use. As we have worked with the system and demonstrated it to a number of our colleagues, many ideas have been discussed which would improve mission accomplishment through some application of RDSS. The list is long but some of the more promising are:

National Emergency Reporting System

This innovation is presently being accomplished with the development of new software. When completed in early 1992, the system may be used, either on the Flight Track console or as a stand alone system, as a clearinghouse and notification center for all accidents or incidents requiring assistance. The Emergency Response Specialist will be notified of an emergency either by the RDSS system or on the toll free telephone line in the Flight Track Center. Working with the big screen and detailed mapping, the Specialist zooms down to a working area on the screen centered on the incident. A pull down menu of emergency services available in that area appears on the screen. Using the computer mouse, the specialist clicks on the response services needed and gets an autodial out on a bank of modems. Within seconds, the specialist is on a live conference call to all of the services at once and is able to dispatch needed help. This system will save minutes or even hours in responding to an emergency. It will facilitate the fulfillment of the DOI commitments to the Federal Emergency Management Agency (FEMA) in the event of a major disaster. It will reduce human suffering and property damage and largely eliminate the confusion which always accompanies a major incident. This service will act as a National 911 service for that other 99% of the country not served by metropolitan 911 dispatch.

DOI Owned Aircraft - Fleet Management

Maintaining the maintenance system for the 85 DOI owned aircraft is a herculean task. Maintenance scheduling and component replacement are based on a knowledge of aircraft flight time. Currently, that time is extracted from paper records submitted to the Office of

Aircraft Services as much as 30 days in arrears. The new computerized fleet maintenance system at OAS is dependent upon timely input of flight time for each aircraft. Boise Flight Track is having an interface developed (at no cost to the government) which will input the aircraft flight time from the recording Hobbs meter or tachometer into the RDSS unit aboard. The information would be automatically transmitted each flight and the Fleet Manager have a real time knowledge of each aircraft status. Simply having this knowledge in real time will save several work months of research each year and maximize availability of the aircraft. The system digital communications capability will also allow the pilot to send unscheduled maintenance and repair needs to OAS even as the aircraft is in flight. Repair services can thus be waiting for the aircraft as it returns for landing.

Command and Control

The essence of directing people in the field is first to know where they are and then to communicate. Movement of vehicular assets in difficult situations such as firefighting and law enforcement require nearly constant knowledge of position and movement. RDSS can provide continuous location information to the incident commander and at the same time offer a silent, secure means of communication. The information is available in the field by using a laptop computer to display vehicles on the map. The information is available in remote locations by data downlink using VSAT satellite communications and a portable satellite dish antenna connected to the laptop computer. By zooming into the area of interest on the map display, excellent detail is available and all vehicles involved are located.

In complex situations, limited radio frequencies often become overloaded. Fully half of this radio traffic involves positioning..."November 12345, say present position and ETA at the incident"....."Roger, this is November 12345. We are approaching the north side of Windy Ridge and estimating your location in 10 minutes." Eliminating this radio traffic and freeing the channels for more appropriate uses will improve efficiency and safety.

Logistics Management

Logistics management primarily involves the obtaining of material assets and the delivery of them to the working level. Key to all logistics management is knowing where the assets and their modes of transportation are at any given time. As we have shown in previous examples, RDSS offers the knowledge of transportation vehicles not possible with any other means. RDSS also offers the ability to monitor the location of individual items of equipment or supplies being moved in vehicles. These can be tracked as individual items or as lots of materials such as pallets or containers by using "smart cards", tiny, inexpensive, microcircuit transponders attached to the loads. The smart cards respond with a unique binary data string when they are moved past card readers. These devices can be located several yards from the movement path of the loads. The card readers are attached to RDSS terminals and the data transmitted to the user console as the items move. Card readers are installed as permanent fixtures at shipping docks or staging areas and may also be installed in cargo aircraft. In the aircraft they are ported to the onboard RDSS system. In this way, a chain of custody is established for each lot being shipped from the time it leaves the warehouse until it is off loaded at the destination. If monitoring is being accomplished, shipping errors can often be corrected before the vehicle leaves the pickup point.

Law enforcement functions are significantly enhanced by the silent, secure communications features of RDSS. Boise Flight Track has been working very closely with several law enforcement agencies and has developed procedures and protocols for classified missions. The Boise Flight Track facility was constructed to safeguard sensitive law enforcement tracking and communications information and the incumbent personnel are cleared for this type of operation.

Automatic Dependent Surveillance (ADS)

From time-to-time it is desirable to monitor remote locations for intrusion, trespass or other illegal activity. Particularly susceptible are areas harboring pilferable equipment, petroleum or mining locations subject to theft and sensitive land areas. Given the vast areas of Federal responsibility, law enforcement and security personnel can only hope to spot check such locations. We can greatly enhance these security activities by using a suitcase sized, solar powered RDSS system attached to any common intrusion detector such as seismic, microwave of infrared. The entire system is easily camouflaged. When the intrusion detector is triggered, it sends a preprogrammed message to the monitoring console and sounds an alarm. If the responding law enforcement vehicle is equipped with RDSS, the operator can monitor it's progress and vector

it directly to the site of intrusion. Authorized vehicles entering the area can be equipped with smart cards and by passing camouflaged readers can preempt the intrusion alarm system.

Hazardous Materials Transport

Surface vehicles carrying hazardous materials can be equipped with briefcase packaged portable RDSS units. If the vehicle stops enroute or deviates from approved routing, investigation is facilitated. Illegal dumping of hazardous waste can be detected in this way. Critical materials characteristics such as temperatures or pressures can be continuously monitored using common transducers and porting their output into the RDSS system. The information is always available at the monitoring console and abnormal trends can be acted upon before they result in an accident. In the event of an accident, the vehicle operator can send an emergency message instantly. Should the vehicle stop transmitting, the situation is treated as an emergency and assistance is dispatched.

Boise Flight Track is currently studying the integration of portions of the CAMEO II emergency response system into the flight track system. CAMEO II was designed by NOAA primarily to respond to hazardous materials accidents. We have found certain aspects of it which may enhance our response to aviation accidents. If we are successful, the integrated systems will greatly improve the ability to respond to both types of accidents.

Aerial Surveys

(Wildlife censusing, wilderness monitoring, pipeline patrol, powerline patrol) Typical of this type work is the need to identify something on the ground and record the time and location. In past, this has usually been done by taking written notes while flying the aircraft or by speaking into a voice recorder and recording the event, time and location by reference to displayed LORAN coordinates. Following the flight, the pilot might spend the next two days transcribing the data into a written report. Bruce Conant, the Wildlife Biologist/Pilot of N-754, has devised an innovative keyboard shorthand using his RDSS system. As he flies over something he wishes to record, he enters the information on the keyboard using only a few keys. He then touches the "Send" button and the information is automatically tagged with the date/time group and location as it appears on the console, a few seconds later. As he is returning to home base, the console operator sorts those messages from others received and prints the report. As he is landing, the completed report is being faxed to the pilot's office.

AUXILIARY CONSOLES

The information from a mobile transmitter can be tracked simultaneously on any number of consoles. There is a small additional fee for this service. When the flight following system becomes operational, that system needs be devoted solely to flight tracking and emergency response. Other functions such as command and control, logistics management and natural resources management should rightfully be performed by the professionals trained in those disciplines and they should have their own information displays for those purposes. The equipment cost is reasonable and in line with similar computer based systems. The console is not a standard computer but is specially built by Railstar. When not being used for tracking, it can be used for any common PC computer functions.

ANALYSIS AND SUMMARY

The RDSS system is a viable and cost effective solution to the dilemmas of flight following and emergency response. The potential for saving lives and reducing human suffering has no price tag. Beyond those considerations, the system offers a myriad of mission enhancements and cost savings which would pay for itself many times over. In the conterminous 48 states, and Alaska, the system is ready for implementation. Our testing in Hawaii is incomplete. We have gathered data for about one third of Hawaii to date.

Boise Flight Track Center is hard at work developing refinements and applications enhancements for the improvement of flight safety and natural resources management. One such project is the incorporation of special use airspace information into the system. When completed, that improvement will provide a new tool for mid-air collision avoidance. We welcome suggestions, comments and visitors. We would also welcome the assistance of anyone with a high degree of expertise in any of the disciplines discussed here and who would like to work with us.

RADIO DETERMINATION SATELLITE SERVICE (RDSS) FUTURING

The original presentation of RDSS was in response to a white paper issued by the National Flight Following Task Force. (R.J. Rivers 2-23-88) The Task Force studied fifteen different flight tracking systems and made specific recommendations regarding administrative and technological changes which would resolve deficiencies in the flight following program.

The RDSS project began early in 1988 to test its capability and potential for flight following of aircraft. Aircraft equipped with the system have been tracked in all areas of the U.S., Alaska, parts of Canada and Siberia. Consoles are operating in Alaska, Arizona, California, Idaho, and Nevada with the coordination center housed at BIFC, Boise, Idaho.

We now have a complete understanding of the potential applications of RDSS within the Bureau. This understanding allows us to prescribe a program for the development of a fully operational flight tracking system.

Ultimately the RDSS will be functional in all field offices by 1995 with a system which facilitates two way data communication with RDSS equipped aircraft, is independent of the A.M. radio network, and provides an automatic alert in case of emergency or loss of contact.

This document outlines the phased implementation of the RDSS project with continued growth and decentralization in out years.

The final approval by the Bureau Field Committee is based on a unanimous agreement on the following points. First is agreement on the Bureau-wide need to continue program development, maintain a small support group in BIFC, and decentralize system use to the field offices. The second point is that field users perceive as much benefit from the RDSS system capacity for two way communications, logistical coordination, and geographic position locating, as that achieved by the flight tracking of aircraft. Therefore, RDSS will be fully integrated with existing logistics centers in all offices, with intent to be made available to all potential users.

Following is a specific description of the program implementation requirements associated with the RDSS initiative.

RDSS PROGRAM IMPLEMENTATION

Implementation in 1993 requires that basic organizational needs must be addressed. The RDSS is approved as a stand alone flight following system meeting the requirements of Departmental and Bureau policy. The operational criteria are as follows:

A) System operation at BIFC will be required 7 days per week during the field season April - September. (6 months/yr)

B) The system will be operational only on a normal dawn to dusk work shift.

C) Off season operations will be provided on a 5 day week, 8 hour day basis.

D) Alaska Fire Service will backup the BIFC system in season, as allowed by current staffing levels.

E) States which have purchased monitors and trained operators will assume responsibility for assimilation of RDSS with existing flight following procedures.

F) States which have the airborne equipment but not a local console, may utilize BIFC -RDSS center for data acquisition and transfer to the State via IAMS. All aircraft will be flight followed in accordance with Bureau policy.

G) Operating costs, line charges, and any associated fees will be borne by the user.

H) FTE and payroll for dispatchers will be borne by the hiring office/unit when operational in the field offices.

I) Equipment purchases will be borne by the unit/office operating the aircraft.

J) Dispatchers in field offices will require one on one training to be provided by the BIFC RDSS support group.

K) Beginning in 1993 RDSS will be added to all new contract specifications. This method increases hourly flight rate which is paid by the user. It is the State's option to specify that airborne RDSS equipment purchased by the contractor becomes Government property at completion of a contract period.

BUDGET

Establishment of the BIFC Aviation Support Group requires an initial assessment in FY 1991. This assessment of $ 140,000 will be covered within existing base from the Fire Presuppression (1520) account until the appropriated funds are available in '93.

States are responsible for their continuous operating costs and for hourly line charges in all years.

BIFC is authorized funding and 4 FTE for the Aviation Support Group.

PORTABLE RDSS EQUIPMENT

Motorola has prototype unit designed with estimated price at $ 4500 each.

This unit requires modification for external A/C antenna and RS 232 port.

Below is the estimated requirement for portable units required for rental aircraft use in all States:

AK 40, CA 30, NV 30, OR 40, Other States 10 ea.; TOTAL 220 units. A request for capital expenditure will be included in FY 1993 PYBP by WO 740. to cover this purchase in the amount of $ 1 Million.

The Washington Office Division of Fire and Aviation will provide policy and fiscal direction for this program. The Director BIFC will coordinate field implementation and technical support. Further information regarding implementation of the RDSS is available by contacting Ron Hanks, Aviation Program Manager at FTS 653-8800.

APPENDIX B

SATELLITE POSITIONING TECHNOLOGIES QUESTIONNAIRE

RESPONSES

1. What do you feel is your level of knowledge of "Satellite Positioning Technologies" (SPT) on a scale of 1 to 4? (1 = no knowledge; 4 = comprehensive knowledge)

BIFC	— 3	One person
SC	— 2	Two people, both - 2
AK	— 3	Two people, 2.5 and 3
AZ	— 4	One person
CA	— 2.5	Two people, 2 and 3
CO	— 3	Two people, 2.5 and 3
ES	— 2	One person
ID	— 3	Four people, all - 3's
MT	— 2.5	One Person
NV	— 2	Two people, both - 2
NM	— 4	One person
OR	— 3	One person
UT	— 3	Two people, 2 and 4
WY	— 3.5	Two people, 3 and 4
WO-600	— 2	Four Division Chiefs, 2, 2, 2, 1
USFS	— 2.6	R-2 =3; R-4 =3; R-5 =2; R-6 =3 & 2
FWS	— 1	Portland, OR Region
BOR	— 2.5	Sacramento Region

2. Which disciplines, within your state office, employ SPT?

BIFC	—	Aviation, fire
SC	—	Cadastral survey
AK	—	Cadastral survey, fire
AZ	—	Archeology, range, recreation, wilderness
CA	—	Cadastral survey, geodesy, lands, law enforcement
CO	—	Cadastral survey, resource management, law enforcement, recreation
ES	—	None
ID	—	Cadastral survey, resource management, Birds of Pray, fire & fire burn areas, engineering, archeology, cultural resources, wildlife, paleontological work, OPS, range
MT	—	Cadastral survey, some DO resource uses
NV	—	Railstar system: Aviation (in support of programs) Ground based systems: fire, wilderness, law enforcement, wild horses and burros, cadastral survey
NM	—	Cadastral survey, law enforcement, GCDB, Resources - vegitation maps
OR	—	Cadastral survey, forestry
UT	—	Cadastral survey, recreation, GIS, resources, law enforcement, operations, minerals
WY	—	Cadastral survey, resource mapping, fire reclamation, fire mapping, cultural activities, archeological siting, Wilderness Study Areas, road location updates

APPENDIX B

2. (Continued)

USGS — Used by the Mapping Division to establish longitude and latitude of different points used in developing maps.
Water Resources Div. uses for well positioning, subsidence, etc.

USFS

R-2 — All RO staff groups and all aspects of forest management on the Forests.
R-4 — RO and Forests – All aspects of Timber Management, engineering, GIS
R-5 — Land surveying and Timber Management
R-6 — Engineering, land surveys, fire, and resource management.

FWS — None
BOR — Land surveying, photogrammetric control

3. Are you aware of any disciplines that would like to employ SPT but haven't? If so, why not?

BIFC — Resources
SC — Mapping, photogrammetry, resource applications, inventory, monitoring, and planning — Lack of training, equipment
AK — All resource programs — Lack of funding
AZ — Wildlife habitat management – ?
CA — Range, resource protection, archeology, timber mgmt. — No funding for equipment
CO — Resources — lack of familiarity with the equipment and costs
ES — Cadastral survey
ID — Cultural resources, all districts, operations, GIS people — lack of knowledge, selective availability, lack of money and support people.
MT — Resources – ?
NV — All resources, etc.
NM — Archeological work, monitoring, hazardous waste, fire management, mapping, resource protection, resource program management – lack of funds
OR — Other resources, archeology, engineering
UT — Law enforcement, engineering — Lack of knowledge and money
WY — Operations, most resources — lack of money, no organizational mechanism in place to share technology

USFS

R-5 — Law Enforcement, cultural resources, — Dollar constraints
R-6 — Fire resources, engineering, — Funding constraints (Forest)

FWS — FWS – regional level (Oregon) is not aware of GPS and its uses.

4. Please identify the various "positioning technologies" that your state office has employed. (1 = method not used; 4 = method used considerably)

BLM	BIFC	SC	AK	AZ	CA	CO	ES	ID	MT	NV	NM	OR	UT	WY	AVE.
a. Terrestrial Surveying	3		4	4	2	4	4	4	4	2	4	4	4	4	3.6
b. Doppler	1		2	2	4	3	1	1	2	1	1	2	4	2	2.0
c. GPS	2		3	3	4	4	1	4	4	2	3	4	4	3	3.2
d. Loran	4		4	1	2	1	1	4	1	4	1	1	4	2	2.3
e. Inertial	1		2	1	2	1	1	1	1	1	1	1	4	1	1.4
f. RDSS	4														–
g. Aerial Photography								4			2			4	3.3
h. MSS & TM								3							–

4. (Continued)

BLM	BIFC	SC	AK	AZ	CA	CO	ES	ID	MT	NV	NM	OR	UT	WY	AVE.
i. Radio										3					–
j. Airborne Cadastral Survey													2		–
k. ABC													4		–
l. Photogrammetry											3			4	3.5
m. Map Digitizing											3			4	3.5

OTHER AGENCIES	USFS— R2	R4	R5	R6	FWS	BOR	AVE.
a. Terrestrial Surveying	3	1	1	2	1	1	1.5
b. Doppler	1	1	1	1	1	1	1.0
c. GPS	2	3	2	4	1	4	2.7
d. Loran	1	2	1	2	1	1	1.3
e. Inertial	1	1	1	2	1	1	1.2

5. Have you taken a course in satellite positioning? (# interviewed) Yes: No:
a. If yes, how many courses have you taken?
b. Was the course(s) beneficial? Please provide details.

BIFC — (1) Yes — 1 — ?
SC — (2) No
AK — (2) 1 — No, 1 — Yes 3 courses — all beneficial
AZ — (1) Yes — 1 — very beneficial
CA — (2) No
CO — (2) Yes — (1 had 1, and 1 had 3 courses) — they were beneficial
ES — (1) Yes — 1 — beneficial
ID — (4) All No
MT — (1) Yes — 1 — beneficial
NV — (2) No
NM — (1) Yes — 6 — all very beneficial
OR — (1) Yes — 3 — All beneficial
UT — (2) Yes — (1 had 1, and 1 had 3 courses) — very beneficial
WY — (2) Yes — (1 had 1, and 1 had 3 courses) — were beneficial
USFS — (5) 2 — No, 3 — Yes — (2 had 1, and 1 had 2 courses), were beneficial
FWS — (1) No
BOR — (1) No

6. What type of equipment, if any does your state have? Please specify:
a. In which division, branch or office is the equipment located?
b. What type of SPT software is used in conjunction with the equipment identified above?

State	Manufacturer	Model	No. of Units	Location	Software
BIFC	Railstar		20	Aviation	Scantrack, Fleetview
	Sony		3		
	Hughes		2		
SC	Trimble Navigation	Pathfinders	4	Cadastral Equip. Cache	Trimble & Motorola Software
	Motorola	Eagle	11		
AK	Railstar		5	Aviation	Railstar
AZ	None				
CA	Trimble Navigation	4000 ST	3	Br of Cadastral Survey	Trimvec
CO	Trimble Navigation	Pathfinder	1	Law Enforcement	Trimble Post Processing
ES	None				

APPENDIX B

6. (Continued)

State	Manufacturer	Model	No. of Units	Location	Software
ID	Trimble Navigation Ashtech	Pathfinder LSII	2 1	Boise District Office	Post processing - Coordinate conversion
MT	None				
NV	Railstar	Scantrak	6	Throughout NV SO	Railstar software
NM	Trimbel Navigation Trimbel Navigation	4000 ST Pathfinder	3 1	Cadastral Survey	Trimbel softwares, Columbus
OR	Motorola Trimble Navigation	Eagle Pathfinder	2 4	Eagles - SO-942 Pathfinders - 2-Medford, 2- Eugene	Motorola software, Geolab Trimble software " "
UT	None - Use Cadastral Equipment Cache				
WY	Motorola	GoldenEagle	3	Cadastral in Gillette	Motorola software, Geolab, NOAA, USGS
USGS	Trimble Navigation	Pathfinder	Many		
USFS R-2	Trimble Navigation	Pathfinder	7	Regional Office - 2 Forests - 2	Trimble software, Autocad " " "
USFS R-4	Motorola Trimble Navigation	Eagle 4000 ST	2 3	RO - Cadastral & Lands	Trimvec, Motorola software
USFS R-5	Trimble Navigation Trimble Navigation	Pathfinder 4000 ST	3 2	Geodetic in Survey Resource Grade - Timber	Trimvec Mgmt. Trimvec
USFS R-6	Trimble Navigation Trimble Navigation	Pathfinder 4000 ST	40-45 3	Pathfinder - Forest Level 4000 ST - RO	Trimvec "
FWS	None				
BOR	NONE yet				

7. Does your state plan to purchase any satellite positioning equipment in the next 5 years? Yes/No If yes, please provide the following information.

State	FY	# Units	Intended Use	Who will use it
BIFC	93	220	Flight following	All aviation users
SC	91	5	Mapping & verification	Cartographers/Resource Spec.
	92	1	Field testing – resc. applic.	Resource Specialists
	92	10	Mapping & verification	Cartographers/Resource Spec.
	93	5	" "	" " "
AK	93	?	Aviation Equipment	
AZ	91	10	Resource Management	Resource Specialists
CA	91	12	Resource Mgmt./Geodesy	Resources & Cadastral Surv.
	92	14	" " "	" " "
	93	2	" " "	" " "
ES	NONE			
ID	91	5	Mapping/Resource Mgmt,	Resource Specialists
	92	1	" " "	" "
	93	3	" " "	" "
	94	1	" " "	" "
	95	2	" " "	" "

7. (Continued)

State	FY	# Units	Intended Use	Who will use it
MT	NONE			
NV	91	1	Flight Tracking (FT)	Fire
	92	5	" " and mapping	Fire
	93	30	(Handheld) FT & "	All Subactivities
NM	93	?	Resource Management	Specialists in the DOs
OR	91	?	Resource Management	Resource Spec. (DO & RA)
	92	?	" "	" " "
	93	?	" "	" " "
	93	3	Geodetic Positioning (Cadastral & mapping control)	Cadastral surveyors
UT	91	2	Locating trails, Archeological sites, etc.	Resources & Operations
	91	2	Cadastral & Resources	Cadastral & Resources
	92	1	Law Enforcement	Law Enforcement & Cadastral
WY	91	3	Cadastral Survey	Cadastral surveyors
	93 est.	8	Resource Management	Resource Specialists
USFS				
R-2	91	15+	Resource Mgmt./Geodetic	Resources & Surveying
	92	15+	" " "	" "
	93	15+	" " "	" "
	94	15+	" " "	" "
	95	15+	" " "	" "
R-4	91	6	Resource Management	Forest Resource Spec.
	92	6+	" "	" " "
	93	6+	" "	" " "
	94	6+	" "	" " "
	95	6+	" "	" " "
R-6	91	20	Resource Management	Forest Resource Spec.
	92	20	" "	" " "
	93	20	" "	" " "
	94	20	" "	" " "
	95	20	" "	" " "

8. Does your state office coordinate activities, contribute funding, or discuss satellite positioning issues with other Federal, State, or local government agencies? Yes/No If yes, please provide a brief description.

BIFC — Have lead for coordination and implementation of RDSS within BLM
SC — Have developed & established contacts with the FS, USGS, and DMA concerning applications and developments in GPS technology.
AK — Coordination with OAS, FWS, NPS, USFS, DOD, FAA & State of Alaska; member GPS user group in Alaska.
AZ — Some cooperation work with Bureau of Reclamation.
CA — Coordinate with USFS - R-5, share knowledge about GPS.
CO — SO involved with the Colorado State Highway Dept. in implementing a State wide High Precision Network. Other activities with counties, local government agencies, and other federal agencies for specific projects.
ES — Not sure
ID — Have coordinated with USFS, USGS, and ARS.
MT — Discussions with USFS.
NV — Are coordinating with USFS, NV Div. Forestry on joint fire operations.

8. (Continued)

NM — Are coordinating with the NM State Highway Dept.; NM Geographic Information Council in implementing a statewide High Precision GPS Network; NGS; USGS; Bureau of Reclamation; and State, County and City agencies.

OR — Are members of Oregon & Washington GPS User Groups composed of private and public sectors (federal, state, and local). The Groups coordinate GPS primary net, technology sharing, and data sharing.

UT — Involved with cooperative efforts in permanent GPS installations – cooperative pools with state, city, county utilities, USFS, etc.

WY — Coordinate with USFS, USGS, NOAA, NGS, and State agencies.

USFS

R-2 — Coordinates with States of Colorado and Wyoming, BLM SOs, NGS, and USGS.

R-6 — Coordinates with BLM

9. Who else do you feel could provide us with additional information on satellite positioning activities within your state? Please provide name and telephone number.

BIFC — Ron Hanks FTS 653-8800; Steve Chivers FTS 554-1218
Bob Evans (907) 257-1378; Marv Robertson (907) 355-5500

AK — Don Henrickson FTS 268-4168; Joe Burns (907) 267-1419

ID — Dwane Olson; Bill Hagdorn FTS 554-1785

MT — Kurt Wurner FTS 588-7720

NV — Len Sims FTS 469-6590; Dave Wolfe FTS 469-6557
Kevin Hull FTS 469-6455; Neil Forsyth FTS 469-6542

OR — Alex Nagygyor (503) 683-6960; Steve Armitage (503) 770-2333

UT — Bob Milton (801) 259-6111; Carla Garison FTS 581-4054

USFS

R-4 — Kent Miller FTS 588-6494

R-5 — Mike Harbin; Kent Whitaker; Bill Snow; Howard Whitman

R-6 — Phil Drake; Dennis Mouland; John Leonard

BOR — Don Stackhouse FTS 460-5015

APPENDIX B

SATELLITE POSITIONING TECHNOLOGIES
Questionnaire
Contact List

OFFICE	CONTACTS	TELEPHONE #	INTERVIEWER
WO-200	Terry Reed (WO-200)	FTS 268-4896	
WO-600	Jean Juilland (WO-680)	FTS 268-4147	
WO-700	Robert Scruggs (WO-720)	FTS 653-8798	
	Brian Dean (WO-740)	FTS 653-8800	
WO-800	NONE at this time		
Service Center	Jon Abrams (SC-678)	FTS 776-0179	
	Jerry Fiedler (SC-678)	FTS 776-0181	
	Tim Geary (SC-678)	FTS 776-6013	
	Robert Mandzi (SC-678)	FTS 776-8865	
	Fred Batson (SC-671)	FTS 776-6376	
	John Baker (SC-325)	FTS 776-8858	
BIFC	Dennis Lamun	FTS 334-1223	Dean
Alaska	Mary Hartell (AK-920)	FTS 869-1409	Reed
	Kristin Staffeldt (AK-920)	FTS 869-1201	Reed
	Paula Krebs (AK-924)	FTS 868-3160	Reed
	Jim Johnson (AK-970E)	FTS 869-1220	Reed
Arizona	Dean Wise (AZ-942)	FTS 261-5544	Reed
California	Lance Bishop (CA-942)	FTS 460-4775	Bishop
Colorado	Randy Bloom (CO-942)	FTS 554-3826	Abrams
	Mary Beth Broe (CO-942)	FTS 554-3828	Abrams
Eastern States	Kenny Ravnikar (ES-942)	FTS 277-0705	Reed
Idaho	Jeff Lee (ID-942)	FTS 554-9686	Dean
	after 1/8/90	FTS 327-3146	
	Janis VanWyhe (Shoshone DO)	FTS 554-6130	Dean
	Deanna Dyer (Boise DO)	(208)384-3481	Dean
	Mike Beatty (Boise DO)	FTS 554-1785	Dean
Montana	Roy Leedy (MT-942)	FTS 588-7726	Reed
	Frances Rieman (MT-931)	FTS 588-7932	Reed
Nevada	Hugh Carson (NV-945)	FTS 469-6457	Walker
	Alan Dunton (NV-945)	FTS 469-6450	Walker
New Mexico	Jay M. Innes (NM-942)	FTS 476-6230	Reed
Oregon	Ken Bays (OR-942)	FTS 392-7135	Walker

APPENDIX B

SATELLITE POSITIONING TECHNOLOGIES
Questionnaire
Contact List (Continued)

OFFICE	CONTACTS	TELEPHONE #	INTERVIEWER
Utah	Donald Buhler (UT-943)	FTS 581-4135	Walker
	Tom Jensen (UT-950)	FTS 581-4054	Walker
Wyoming	Bruce Keating (WY-941)	FTS 329-6245	Dean
	Donald Patterson (WY-942)	(307)686-6750	Dean

SPECIAL INTERVIEWS

Service Center	All contacts	Abrams
BLM WO	All contacts	Scruggs/Juilland/Schrott
Forest Service and all other Federal agencies in the field, except Geological Survey.		Bishop
Geological Survey both in WO and the field.		Juilland/Schrott
Forest Service and all other Federal agencies in the WO.		Scruggs
Private and State governments efforts in Satellite Positioning Technologies.		Abrams

APPENDIX C

DEPARTMENT OF THE INTERIOR
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DENVER, COLORADO 80225-0047

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9600 (SC-678)

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November 8, 1989

Information Bulletin No. SC-90-030

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LEAD RESP

To: All Field Officials

From: Service Center Director

Subject: Discussion on Global Positioning System (GPS) Applications for BLM

Major implementation of the NAVSTAR Global Positioning System (satellite positioning) at operational levels appears to be imminent within the next two years. We want to call attention to and emphasize that although the impact of GPS for cadastral survey and other measurement entities in the Bureau approach revolutionary potentials, the market and proclivity of this technology for other Bureau disciplines, e.g., resources, law enforcement, etc., constitute a much larger area of the spatial positioning spectrum.

Attached is an overview and update of GPS technologies relative to cadastral survey applications. It is being furnished to alert and orient you to some of the potentials for GPS use in the Bureau. Questions may be directed to Jerry Fiedler, FTS 776-0181, or to an appropriate cadastral survey office within your organization.

Signature

DSCD, Administration and Technical Services

1 Attachment
BLM SURVEYS & NAVSTAR GPS (7 pp)

Distribution
WO-720, Premier, Rm 201
SC-324A, BLM Library
SC-658, SC Reader File

BUREAU OF LAND MANAGEMENT SURVEYS AND THE NAVSTAR GLOBAL POSITIONING SYSTEM

Jerry Fiedler, Geodesist

Service Center
Branch of Cadastral Survey Development

ABSTRACT

This report defines and describes Global Positioning System (GPS) surveying methods relevant to Bureau of Land Management Cadastral Survey. It addresses the possibility of GPS applications to other areas of BLM activities such as engineering, mapping and resource management. In addition, it summarizes the present, (fall 1989), GPS positioning capabilities that are achievable with existing hardware and software.

INTRODUCTION

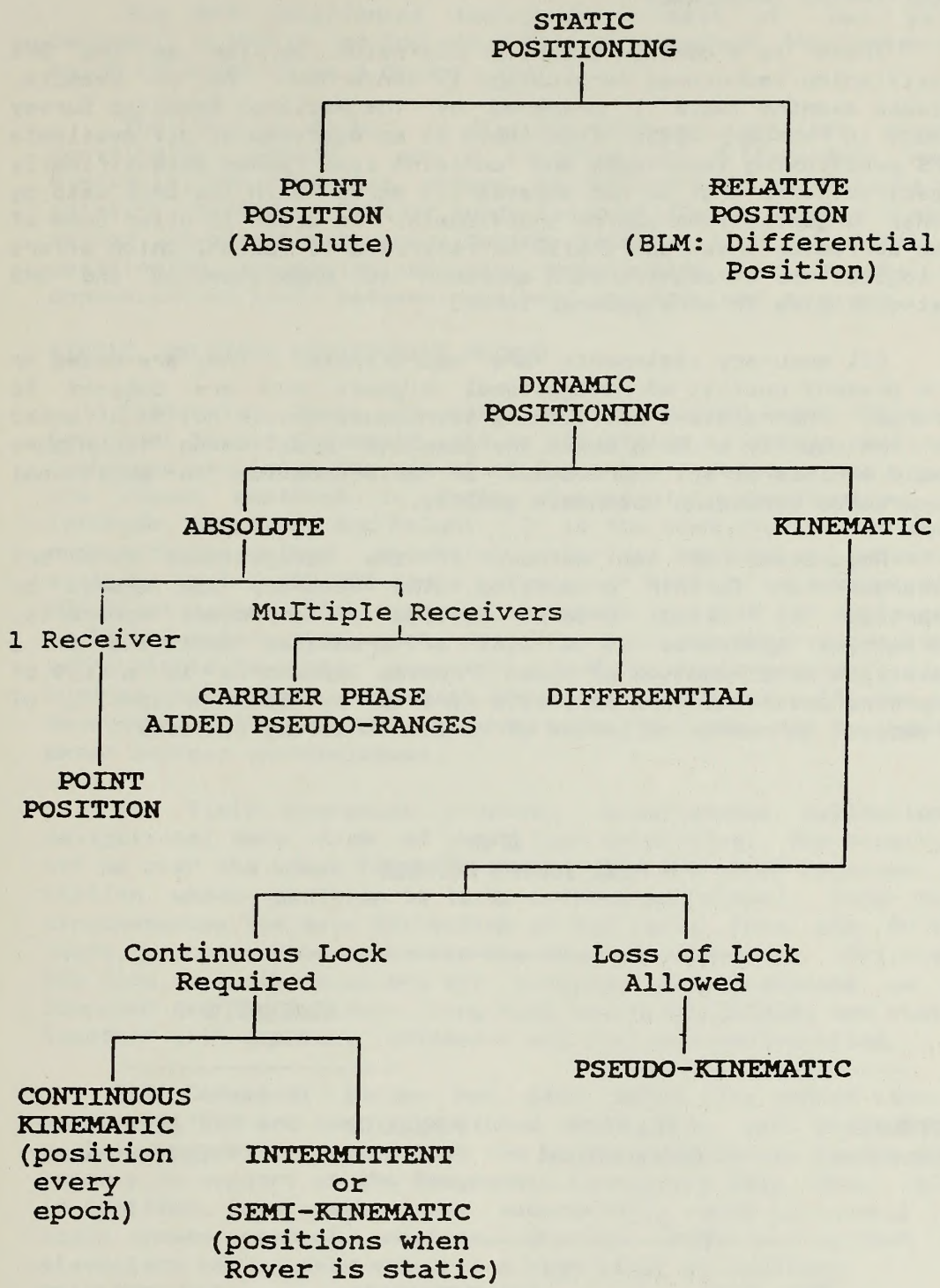
The GPS satellite positioning system consists of the space, control and user segments.

The space segment consists of eleven Block I (prototype) satellites which have been launched since 1978, seven of which are still operational. The first Block II (operational) satellite was launched on Feb. 14, 1989; since then, two more satellites have been made available to the user segment. There will be a total of 24 Block II satellites (21 active plus three spare) positioned in six orbital planes each containinig four satellites in the final constellation. This configuration will provide almost full global coverage 24 hours a day. It is planned that the Block III satellites, presently being designed, will replace Block II around the year 2,000.

The satellites orbit the earth every 12 hours at an approximate altitude of 20,000 kilometers. Each satellite transmits on two carriers, L1 and L2, at 1,575.42 MHz and 1,227.60 MHz, respectively. The L1 is modulated by C/A code and either P-code or Y-code. The L2 is modulated by P-code or Y-code.

The control segment of the GPS consists of five stations around the world that monitor and communicate with the satellites. The master control station is in Colorado Springs, Colorado.

The user segment, both military and civilian, employs different types of receivers to collect navigational data to determine geodetic or geographic positions with various degrees of accuracy.



Absolute and Point Positions are relative to a coordinate system.

Kinematic and Relative Positions are relative to the other receiver(s).

TABLE 1

POSITIONING TECHNIQUES

There is a certain amount of confusion as far as the GPS positioning techniques terminology is concerned. As an example, please examine Table 1 prepared by the National Geodetic Survey (NGS) in February 1989. This table is an overview of all available GPS positioning techniques and contains some rather scientifically specific terms that do not necessarily agree with the ones used by other organizations and/or individuals. In order to clear some of the confusion this report will be referring to Table 2 which offers a logical and straightforward approach to understanding the GPS methodologies in more general terms.

All accuracy statements are approximate. They are based on the present quality of navigational signals and are subject to change. The relative positioning techniques should not be affected by the quality of data while the absolute positioning techniques would exhibit direct improvement or deterioration in positional accuracies depending upon data quality.

Regardless of the method, if the navigational data are recorded for further processing, the accuracy can always be improved by using precise instead of broadcast ephemeris. (Broadcast ephemeris is a list of predicted positions of a satellite as a function of time. Precise ephemeris is a list of improved positions of a satellite derived by post processing of broadcast ephemeris collected at various tracking stations).

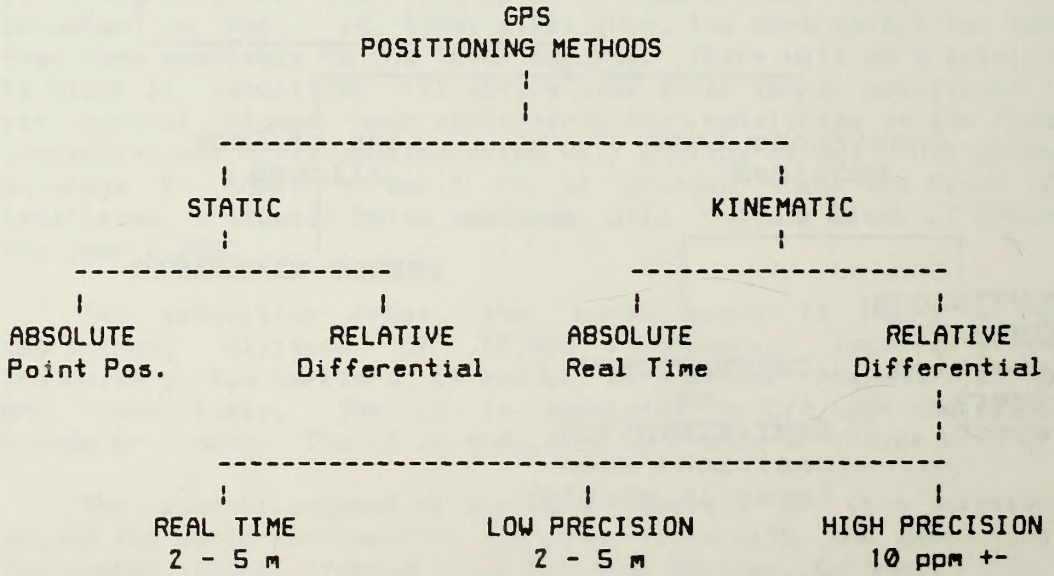


TABLE 2.

The GPS positioning techniques consist of two primary methods: a static method and a kinematic method, the latter often being referred to as a dynamic one.

The static method is divided into an absolute or point positioning method, and a relative or differential method. Similarly, the kinematic method is divided into an absolute and a relative method. Further subdivision of the kinematic relative method is possible by considering factors such as: real time positioning, processing software, maintaining lock on satellites, communication links between receivers and required accuracy.

STATIC, RELATIVE POSITIONING METHOD

Presently, there is only one GPS method being employed by Cadastral Survey personnel. It is the static, relative positioning technique requiring the use of at least two receivers and use of one known position in terms of geodetic coordinates; i.e., latitude, longitude and height. It is the most widely used and the most accurate method, producing relative accuracies between two stations in 1 / 100,000 range (10 ppm) or better, an equivalent to NGS first order. This accuracy statement is valid for distances up to 50 kilometers (or more, depending upon atmospheric conditions) using single frequency receivers, and for distances up to several hundred kilometers using dual frequency receivers. It has been demonstrated that much higher accuracies, 0.1 ppm, may be achieved under certain circumstances.

The field operation involves simultaneous collection of navigational data from at least four satellites. One receiver is set up over the known (master) station and the other receiver at a station whose position is to be determined (slave). Under normal circumstances the data collection period lasts from one to three hours to achieve and guarantee the desired accuracy. Afterwards, the data from all receivers are combined and processed on a PC computer and the latitude, longitude and height of the new station, together with accuracy indicators are analyzed and verified.

BLM Cadastral Survey has been using this method since the spring of 1988 and has established well over one thousand high quality geodetic positions on the Public Land Survey System (PLSS) corners in support of the Geographic Coordinate Data Base (GCDB). In addition, this method was successfully used in several large scale photo control projects, thereby demonstrating that even elevations can be determined to a high level of accuracy.

STATIC, ABSOLUTE POSITIONING METHOD

The static, absolute positioning method requires the use of only one receiver. The results, latitude, longitude and height of the unknown station are relative to the satellite coordinate system WGS-84 (World Geodetic System 1984) and their accuracy may vary from several meters to one hundred meters. This large disparity is directly related to the satellite geometry and the availability and

quality of orbital data; i.e., C/A code, P-code, precise ephemerides, broadcast ephemerides and refraction. Depending on the desired accuracy, the station coordinates may be obtained in a matter of minutes without any post-processing; consequently, a demand for higher accuracy would require data recording and processing.

The method seems to be applicable only in situations where either no existing control is available within many hundreds of kilometers, or the accuracy requirement is relatively low.

KINEMATIC, ABSOLUTE POSITIONING METHOD

The kinematic, absolute positioning method is quite similar to the static, absolute positioning method, i.e., it requires only one receiver and the coordinates are relative to WGS-84. It provides continuous position update in real time without the necessity to record any satellite data, and therefore no post-processing is required. Because of the dynamic nature of this method, the accuracy is of the lowest order of all GPS methods (25-100 meters), and subject to similar conditions as stated for the static, absolute positioning method, e.g., code availability, satellite geometry and quality of broadcast ephemeris.

This method is suitable for acquisition of a large number of positions in a short period of time. The receiver functions in autonomous mode recording individual positions at selected rate, (e.g., one second), and may be mounted on any type of moving platform such as boat, car, helicopter or an airplane.

KINEMATIC, RELATIVE POSITIONING METHODS

Basically, there are three kinematic, relative positioning methods that are of special interest to BLM: 1. real time method, 2. low precision method, and 3. high precision method; each incorporates different software and requires at least two receivers.

1. The real time kinematic, relative positioning method requires a radio/phone communication link between two receivers. As with all kinematic, relative positioning methods, one receiver occupies a station having known geodetic coordinates (master station) while the other receiver moves (rover). Both receivers track the same satellite signals which are immediately processed and the results displayed in real time. No navigational data are recorded or stored. A 2-5 meter real time positional accuracy is possible due to the communication link.

A loss of the radio/phone communication between the two receivers would cause temporary interruption in the data exchange and no reliable positions would be available. A similar situation occurs when either receiver loses lock on satellites. Normal operation resumes as soon as the signals are re-acquired.

This method produces good relative positional accuracy (2-5 meters) in real time; its application is, however, rather limited, due to the difficult logistics of maintaining the required communication.

2. The low accuracy kinematic, relative positioning method employs two or more receivers; field operation is quite similar to the real time method except for the absence of the radio/phone link. Each receiver records the navigational data for subsequent post-processing which yields relative accuracies of 2-5 meters. A satellite signal interruption caused by obstructions results only in temporary loss of data in contrast to high precision method (last method described).

This method provides continuous positioning whose resolution is very suitable for a number of BLM applications such as: inventory of roads, location of structures (bridges, oil and water wells), and various boundary lines depicting wild life habitats. In addition, this method is ideally suited for the establishment of geographic coordinates on PLSS corners to improve and assure the integrity of the GCDB. Tens of positions, using only two receivers, may be obtained during an observational period which is presently about four hours ("window"), gradually changing from day to night in summer and winter, respectively, and improving with every launch of a new satellite.

3. The last method described in this report is the high precision, kinematic relative positioning technique. At the present time, it is the most promising method combining high productivity with accuracies comparable to the static, relative positioning technique.

A typical field operation employs one receiver occupying a known station and recording navigational data for the duration of a survey. One or more receivers track and record the same satellite data within the same period of time and move from one unknown station to another (rover).

There are several important conditions, however, that must be satisfied in order to accomplish a successfull mission.

a. The rover must become stationary at the unknown station for 2-10 minutes.

b. The rover must occupy every unknown station at least twice.

c. All receivers must maintain continuous lock on at least four satellites.

d. If the rover loses lock, it must return to the last occupied station and resume data collection.

From the logistical point of view, this is the most demanding positioning technique and its full potential can be exploited only when the whole GPS becomes operational.

SUMMARY

Several GPS positioning techniques applicable to the needs of the BLM have been presented in this report. They all offer viable alternatives to the traditional methods presently being employed.

The space segment of the GPS is rapidly changing from an experimental to an operational status. The results of research and development in the receiver technology and associated software have produced portable, sophisticated and reliable instruments capable of delivering cost effective and highly accurate positions.

It is important that BLM continues its active role in further exploration of the GPS. It is equally important, that BLM takes full advantage of GPS capabilities and expands its applications beyond the Cadastral Survey.

APPENDIX D

GIS RESOURCE DATA INTEGRATION AND GPS

January 24, 1990

John B. Keating, Jr.

ABSTRACT

The rapid increase in use of geographic information systems (GIS) in all resource activities prompts the need for better tools and techniques to integrate spatial data. The single common thread in a resource GIS is the coordinate location of the data. Recent changes in locational technology, including the increased use of traditional tools in positioning resource data, are reviewed. Costs, accuracies, and suggested ways to attach spatial coordinates to natural resource data and cultural information used in managing our resources are reviewed. Six locational science categories are covered with recommendations: 1. Terrestrial Positioning Systems; 2. Calculated Coordinates; 3. Cartographic Reference Systems; 4. Photogrammetric Systems; 5. Space Remote Sensing Systems: 6. Satellite Positioning Systems. Also addressed are the precision/accuracy versus cost of coordinate location systems and what the future holds with innovations in the locational sciences.

INTRODUCTION

Purpose

This paper is designed to cover a wide range of spatial coordinate determination tools and techniques used in the "locational sciences" for resource based GIS's. Because of limited space, each system is only briefly covered. The reference section will assist further investigations into each method. Brand names in this paper are used as examples only and are not to be considered as an endorsement.

Location is the single most important item in the integration of data in geographic information systems (GIS). The locational coordinates are the common ingredient in diverse resource information that allows the data to be displayed in map form in their correct spatial relationship to each other. Locational data must be stored in a common data structure to ease integration of resource data. It allows the user the ability to combine, compare and analyze data without conversion or transformation of the coordinates. Locational coordinates further assists the resource user in multi-disciplinary analysis, such as BLM's multiple use resource management in which the location of eagle nests can be compared with a proposed coal strip mine location.

A GIS Versus an Information System

Location is the most important component in a GIS as compared to a data base management system(DBMS). While a DBMS can store coordinates of data, it can't spatially process or use the coordinates. Spatial data adds an important dimension to a GIS providing the ability to analyze and graphically display spatially related information with great versatility using computer technology.

Field location of resource data can involve intensive field labor, i.e., months of tracking and mapping locations of a polar bear. Current technology gives us many new tools and techniques to locate and map field phenomena. This paper is about both the common and the unique ways to locate coordinates of natural resource related data.

Coordinate Derivation for Resource Data

In the past, we either took a map to the field or made a map by sketching the resource feature and its location. Some maps had a standard coordinate system base. However, many of the pre-1960 maps did not have a worldwide or absolute coordinate system portrayed on them and only depicted relative location without a coordinate tie. These included many of the Forest Service and Bureau of Land Management maps.

Our more recent resource map bases have worldwide/absolute coordinate systems, including Geographic Coordinates (latitude and longitude) and Universal Transverse Mercator (UTM). Some of our maps use local coordinates that can be converted into a worldwide system, the most commonly known system in the United States is our State Plane Coordinates system used by federal and state transportation departments.

Absolute coordinate systems use both spherical and plane coordinates. These systems both have value in the location and spatial analysis of resource data. All coordinate systems are based on a geodetic description of the shape and size of the earth. We currently use several ellipsoids to describe the best fit for a portion of the world. As our space measurement and computational capabilities improve, geodesists can refine the mathematical description of the Earth or part of the Earth.

A coordinate system transition is taking place in North America, the National Geodetic Survey (NGS) has recently implemented a new North America Horizontal Datum(83) which replaces the 1927 datum. This can cause confusion to the scientist who wants to locate data for spatial analysis in a GIS. All users of coordinates should check the ellipsoid and datum they are using, to avoid mixing coordinates with different datums. Historic data or information that has a long life span should have its base datum recorded, especially for precise locations.

Spherical coordinates are based on a sphere or ellipsoid and are normally reported as latitude and longitude in degrees, minutes, and seconds. Plane coordinates are based on a plane cartesian coordinate system which is tied to spherical locations. One example of a plane coordinate system is the UTM coordinate system, which divides the Earth's surface into 60 north-south quadrilateral zones, each 6 degrees wide. The northing measurement is made in meters from the Equator(0°). The easting measurement is made from the central meridian of each zone. These zones are assigned a false origin of 500,000 meters in the easting direction. These zones are treated as though they are flat or a plane, with the Earth's surface projected onto them.

As with a base datum, care must be also taken to note the map projection of the plane coordinate systems or any map product used to locate or digitize data.

Complex Positioning Systems Interrelationship

Our locational systems are very dependent and each locational technology may be based on other systems. For example, digital geometric positional corrections for Landsat Thematic Mapper imagery use controls from topographic maps, which are produced using photogrammetic surveys that have mapping control surveys tied to a cadastral survey. Cadastral Surveys are tied to geodetic surveys for base control. Each system is based on and dependent on other locational technology. This interrelationship can strengthen mapping accuracies by correlation of the various tools, which can identify mapping errors. But it can also cause systematic error in derived mapping products. Even more modern systems, such as Global Positioning System (GPS), normally use dependent techniques that require geodetic control to record high accuracy geographic coordinates.

Coordinate Locational Tools for Natural Resources

This paper divides locational technology into six tools/techniques categories. There can be overlap in the categories, and more than one tool in a class can be used at a time. Because of the diversity in capabilities to obtain coordinates of resource data, I have grouped some tools into general classes such as Terrestrial Positioning Systems. These groups include a mixture of tools, both manual and fully automated. The six categories are:

1. **TERRESTRIAL POSITIONING SYSTEMS**
2. **CACULATED COORDINATES FROM TIES**
3. **CARTOGRAPHIC REFERENCE SYSTEMS**
4. **PHOTOGRAMMETRY BASED SYSTEMS**
5. **SPACE REMOTE SENSING SYSTEMS**
6. **SATELLITE POSITIONING SYSTEMS**

HISTORIC PERSPECTIVE

Some of the BEST tools have been used most of this century and are considered OPERATIONAL by most scientists that use locational technology. The following locational tools have been used for many years in resource field activities:

map reference	*+100 years*
field mapping from aerial photos	*+50 years*
photogrammetry	*+50 years*
orthophotos	*+25 years*
inertial systems	*+25 years*
navigational satellites	*+25 years*
space remote sensing	*+25 years*
satellite biotelemetry	*+18 years*

Few totally new technologies are expected in the near future, but the current technologies will be honed and improved into affordable resource mapping tools. Because some of these locational tools are used in highly specialized disciplines, knowledge of their use has been very limited in the past. However, because of the increased use of geographic information systems, new resource demand has been created for these locational tools.

TERRESTRIAL POSITIONING SYSTEMS

Traditional Cadastral and Geodetic Surveys

Transit and Theodolite Ground Surveys

System description

Ground surveys have been performed in the United States for over 200 years, mostly for cadastral land description and boundary surveys. The equipment has evolved from simple bearing measuring transits to computer-based total stations/theodolites that measure horizontal and vertical angles in seconds and distance in centimeters, with output to a field data recorder. New surveying equipment includes laser technology to measure distances and angles. But even with the new technology, ground surveying still requires intensive field work and costly technical field crew expertise. The Bureau of Land Management (BLM) is the only federal agency legally tasked to approve federal cadastral surveys. The National Geodetic Survey (NGS), U.S. Geological Survey (USGS) and other agencies perform control surveys for the national control network and for the production of maps.

Main uses

Cadastral surveys are used for legal land location and descriptions. Control surveys are used to form the national geodetic network base for which most other non-land surveys are tied. They are used for mapping and photogrammetric control surveys and engineering location, design and construction surveys. Special surveys tie new points to geodetic control and their coordinates can be calculated.

Resource potential

Traditional ground surveys can measure accuracies in centimeters, but accuracies may range up to meters because of the many different variables involved. Recent resource use includes measuring very minor earth movements across faultlines, to accuracies less than a centimeter in both horizontal and vertical directions to detect the potential for earthquakes. Documented field survey monuments ("Brass Caps") provide good control for the field location of resource data. They can be used for general locations, or accurate survey instruments can be used to measure precise ties.

Precise ground surveys are labor intensive and costly for resource data location. Only very valuable or legal location needs, such as the location of a producing oil and gas well in a potential legal trespass situation, justify the cost of a ground survey tie. Further information may be obtained from the Manual of Survey Instructions, 1973 (BLM, 1973) and various engineering survey books.

Inertial Survey Systems (ISS)

System description

Inertial survey systems(ISS) are based on high precision gyroscopes that, once initialized with control coordinates, can measure the rate of instantaneous change through the use of accelerometers. As a check for accuracy, ISSs should return to known coordinates upon survey completion. They are primarily used on aircraft and shipboard as navigational devices. They have one distinct advantage over most systems in that they give a continuous, real-time record of positions of the ISS unit. The on-board ISS computer can be used to find a location by coordinates. These systems are expensive, the first ground systems cost over $250,000. Until the recent use of satellite point positioning systems, ISS offered the only fully automated field coordinate location system (Hatfield, 1978).

Main uses

The primary uses of ISS are in aircraft and ship navigation. The sub-meter accuracies obtained by the units, when all parameters are followed, make them excellent for control survey extension both by ground vehicle and helicopter. The BLM has been using two inertial systems in Alaska to supplement new cadastral surveys and to identify protracted coordinates in the field. They have been used for location of seismic surveys, photogrammetric control for engineering scale mapping, densification surveys, control for analytical aerotriangulation, mine engineering control, right-of-ways, and other linear surveys The vertical measurement accuracies are approximately half their horizontal accuracies (USFS, 1985).

Resource potential

Although expensive and costly to field operate, the Inertial survey systems are cost effective in locating offshore oil rigs, vessels, bouys, and geophysical and oceanographic data. Their most cost effective resource work is in dynamic situations where good locational coordinates are required. ISS are best used for linear or near linear corridors. Vehicle mounting limits this system to sites accessible by vehicles. Use in an airborne helicopter limits the accuracy of the ISS and requires special flight procedures (USFS, 1985).

Field Use of Aerial Photographs and Maps

The use of aerial photography as a field mapping tool is covered in the photogrammetric section VIII.

Active and Passive Transmitters and Receivers

LORAN "C"

System description

LORAN C radio navigation uses a hyperbolic navigation system in which simultaneous signals from a master station and at least two slave stations are received and interpreted as differences in distance from the stations. These systems give the location in LORAN C coordinates that must be converted into the geographic coordinates of the user system.

Main uses

The primary use of LORAN C is offshore navigation and it is used by both ships and aircraft. There are geographic limitations caused by distance from the LORAN C transmitters.

Resource potential

Where available, LORAN C can be of some resource use. The units are moderate in price and under proper control, accuracies in the range of 30 to 150 meters can be obtained. The resource use includes mapping wildfire locations by aircraft in Alaska and locating and mapping side scan sonar ocean and lake bottom data for GIS analysis (Brown, 1988). The BLM has used the aircraft units in helicopters to find the dropoff points and pickup points for field survey crews. They also have proven cost effective in preprogramming flights to find several field sites spread over a 100 miles in Western Wyoming.

Automated Lightning Detection System (ALDS)

System description

The Automated Lightning Detection System (ALDS), which was implemented by the Bureau of Land Management in the Western United States, uses the Doppler technique from ground stations to detect ground lightning strikes for the BLM fire management program. This system was developed and expanded from 1970 Canadian technology to include the detection and mapping location of 99 percent of ground lightning strikes to an accuracy of approximately one minute of latitude and longitude (±1 mile). ALDS uses direction finders (DF) to detect the unique magnetic and electrical signals produced by all ground strike lightning flashes (Maier, 1983). The signal is uploaded to and transmitted by satellite communications to a positional analysis station in Boise, Idaho. The ALDS measures angular accuracies of ±1 degree for lightning occurring within 100 nautical miles of a DF. The location of the strike is then transmitted via satellite to CRT's with map graphics in 11 Western states (German, 1987).

Main uses

The detection of ground lightning strikes is for the identification and control of lightning-caused wildfires.

Resource potential

The identification of potential fire locations is due to lightning ground strikes. This can reduce the amount of field aircraft inspections and flights during the fire season. The system is also used to indicate the intensity of thunderstorms.

Radio-telemetry

Radio-telemetry has been used since the Second World War. Its initial use was with direction finding antennas to triangulate the location of enemy transmitters. Since the late

1960's, transmitters have been attached to smaller and smaller game to track and plot their location on maps using transmitters in the 164MHz range (Judd, 1977). Tracking has been done using both aircraft and handheld antennas on the ground (Craighead, 1969). Accuracies have been reported to 0.65km using 1:62,500 maps to plot locations (Craighead, 1970). The method of obtaining coordinates is very labor intensive from the ground and loses accuracy from aircraft.

CALCULATED COORDINATES FROM TIES

PLSS Coordinate Computation System(PCCS)

System description

The BLM has developed a unique survey adjustment software that uses geodetic control coordinates tied to the Public Land Survey System (PLSS) and calculates the geographic coordinates of all survey corners. Control for this adjustment procedure can be from GPS, the TRANSIT satellite, ground geodetic ties and/or photogrammetry . The PCCS is the only known coordinate computation software for Federal cadastral surveys. Currently, PCCS runs on both the Honeywell DPS-8 computer and Prime minicomputers. Normal adjustment procedures include: (1) identifying post-1910 cadastral surveys, (2) obtaining geodetic coordinate ties to two or more corners within the adjustment area, (3) encoding coordinate ties and all distances and bearings in the survey, (4) interactivily running PCCS calculations for the coordinates of all corners within the survey. PCCS gives the user an accuracy report in the form of closures within the survey.

Our Wyoming Office normally uses the geographic coordinates of the four township corners obtained by GPS on Doppler techniques. Our closures average around 6 to 10 feet for all adjusted corner coordinates. The resultant output of this system will be uploaded to the Bureau's Geographic Coordinate Data Base (GCDB), with additional survey attribute data. These coordinates do not replace traditional surveys but give the resource manager greater flexibility to analyze our ownership status data and the ability to portray the survey digitally.

Resource potential

The resource potential in PCCS use lies in the secondary use to describe ownership digitally by coordinates. Much of our record resource data can currently only be located by section subdivision (aliquot part), and almost all of our land management decisions involve land ownership status by locations.

Main uses

The PCCS derived coordinates for survey corners are used to produce the landnet cadastre layer for the Bureau's LIS. These coordinates when transferred to our GIS, can be used to portray land and mineral ownership and to assist in automated Master Title Plat (MTP) drafting.

Coordinate Geometry (COGO)

System description

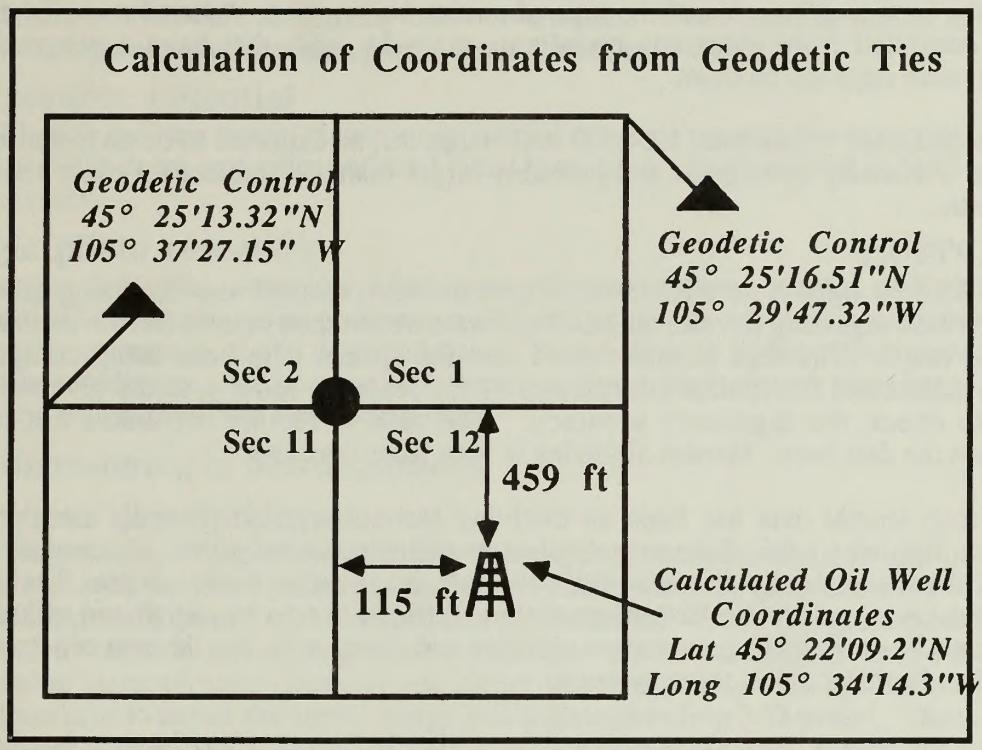
There are many coordinate geometry (COGO) packages that run on mini and microcomputer systems than can compute coordinates from known geodetic control. Our discussion is limited here to two software packages that are in the Bureau's GIS. They are Parcel Generation and calculations of oil and gas well drill pad coordinates using offset survey ties to our cadastral survey that have corner coordinates.

The Bureau's developmental software for graphic parcel generation uses an existing PLSS landnet with corner coordinates to compute simple and complex parcels from a legal description. The parcel coordinates can be projected from existing data bases, such as the BLM's Automated Land and Minerals Record Systems (ALMRS) or from keyboarding of legal parcel descriptions. A graphic map with the new parcels can be plotted on the existing township survey. These COGO determined parcel locations can be used for analysis with

coal data to estimate the volume of coal under a potential lease parcel.

The geographic coordinates of oil and gas wells can be calculated from their survey ties to existing section lines with a BLM program called Geographic Well Locator (GGWL). The well location dimensions are given in feet offset from a section line. First, we obtain the coordinates of the section corners in the GIS, then we calculate the well UTM coordinates using the survey offsets (see Figure 1) to compute the derived well coordinates.

Figure 1



Main uses

COGO's in BLM are primarily used to generate coordinates from distance and bearing surveys with ties to geodetic control.

Resource potential

COGO's can be used as described above or for calculation of point or linear feature coordinates, such as, roads, fence lines, etc.

CARTOGRAPHIC REFERENCE SYSTEMS

Compilation & Capture from Maps/Orthophotos

System description

Topographic maps and orthophotoquads are the workhorse of resource spatial data location and entry into GIS. The orthophtoquad has been evolving over the past 25 years into an excellent mapping tool. Orthophotoquads are aerial photography with all radial, terrain, and lens distortions removed so that they are orthogonal. Resource data can be directly mapped onto topographic maps or orthophotoquads. Data can also be collected on aerial photos in the field and then compiled to maps or orthophoto overlays. The data is then digitized from the map overlays using the spatial coordinates of the map as control.

Main uses

The main uses of cartographic reference tools are for soil, vegetation, cultural, hydrography inventories, etc., especially those that require interpretation and plotting to maps. These tools can be used accurately for locations of point, line, and polygon data.

Resource potential

The use of topographic maps and orthophotoquads as the mapping base for resource data has increased over the last 10 years. Many users require current photography for their mapping tools. Cartographic reference with manual digitizing is currently the least expensive technique for obtaining coordinates for resource data. Accuracies are directly related to the base map's scale and the type of data to be mapped. A lot of resource data has to be compiled from older non-coordinate maps to maps that have a geographic reference system depicted on them.

Accuracies on USGS 7.5 minute, 1:24,000 scale maps can be expected to be no better than ±12 meters if visually transferred and probably larger than ±20 meters for most natural resource data.

DATA CAPTURE

The primary GIS data entry system for resource coordinates is manual map digitizing using a digital tablet. These digitizing devices with GIS software obtain their control from coordinates plotted on the maps. The data is then traced into the spatial data base using computer algorithms to adjust and interpolate coordinates of the feature. Most systems give online coordinates to check the digitizer's accuracy. The related feature attributes are then keyboarded into the data base. Manual digitizing is very labor intensive.

Scanning of map spatial data has been an evolving technology that recently has gained popularity as a digitizing tool. Scanning requires coordinate control points to compute the coordinates of the scanned data. Scanners can be simple, inexpensive video cameras that have both optical and random electronic distortions that are difficult to remove. High-end technical scanners are used by some large government agencies and contractors, but the cost can exceed $1,000,000, thus limiting use of these systems.

Most scanning requires a large amount of editing either before or after the data has been scanned. Scanning, also, encounters problems with data that has been converted from raster to vector and still requires editing. However, raster to vector software is improving.

Attempts to scan data that is not orthogonal (positionally correct) has created subsequent adjustment problems. For example, scanning timber types plotted on aerial photographs in high relief areas creates errors that are close to impossible to correct. Edge matching this data is difficult and requires manual interaction. Any subsequent GIS use of this data with correctly positioned data will immediately show errors.

PHOTOGRAMMETRIC BASED SYSTEMS

Aerial Photographs as a resource data recording tool

System description

Aerial photography is an excellent field mapping and data interpretation resource tool. While aerial photographs are an excellent data collection tool, they contain numerous image distortions that require special geometric corrections and cannot be considered a true locational tool. These corrections can be obtained through photogrammetry, the science of making true measurements from aerial photography, or the data can be transferred to orthophotos. Photogrammetry is more precise, but requires costly stereoplotter equipment. Manually transferring data from photographs to maps is labor intensive and can lose some precision.

Aerial photographs are a key locational tool, but corrected locations can only be produced using stereoplotters and ground control coordinates produced from one of the other locational tools. The ground coordinates are normally pre-selected and panelled prior to flying the photography so they can be photo identifiable. Some types of resource reference data, such as section corners can be panelled prior to the aerial flight so they are easily identifiable on the imagery.

Main uses

Aerial photography are primarily used in photogrammetric stereoplotters to produce orthogonally correct maps. They can be used as a data collection tool for soil surveys, timber, wildlife habitat or many other inventories. When used in simple stereo viewing devices, photos give the interpreter a three-dimensional view.

Resource potential

Although they are one of the strongest natural resource mapping tools, aerial photography, especially color and color infrared film, have been under utilized in land management activities.

Single photo resection

In the past few years, computer-adjustment software has been created to digitize locations directly off non-stereo aerial photography. Some programs use terrain models to assist in a geometric correction of the digitized data. This technique is not recommended to obtain accurate coordinates. It appears to work better with very high altitude imagery or space-based imagery, which have little terrain distortion.

Photogrammetric Stereoplotters

System description

Photogrammetric stereoplotters, precision optical equipment, allow the user to view a stereoscopic model of the earth's surface. If detailed survey ground control is added to the model, precise ground measurement can be performed. When this ground control is tied to geodetic control, direct geographic coordinates can be collected from the stereoplotters. Analog stereoplotters normally use direct image viewing with optical and mechanical adjustment to adjust the stereo image into a distortion-free 3-D model. These models can be scaled and mechanically leveled to fit the earth's surface and produce geographic measurements in x, y, and z. Newer, fully analytical stereoplotters use computers to assist the operator in both model setup and dimensioning the stereomodel to true ground coordinates. Analytical stereoplotters, because of their ease in setup and increased accuracy, are replacing the older analog stereoplotters (US Forest Service, 1985)

Photogrammetry requires detailed ground measurements for control. These measurements are normally obtained through ground control surveys, but more recently they have been derived from satellite positioning devices. All photogrammetric control must be photo identifiable; ground panels can be used to mark the control prior to flying the photography.

Main uses

Direct viewing and mapping of resource data on stereoplotters has been under-utilized by the resource scientists. This tool has primarily suffered because of the expensive equipment and special expertise required to set up and operate a stereoplotter. There has been some use in geologic interpretive mapping (Pilmore et al, 1981) and in wildlife habitat/wetland mapping by the US Fish and Wildlife Service.

Accuracies from photogrammetric systems can vary greatly due to the many parameters involved with mapping. Listed below are estimated accuracies of products produced with photogrammetry:

Type	*Class*	*Scales*	*Est. Accuracies*
Engineering Scales	Large Scale	<1:20,000	±1 cm. to 1 m.
Resource Mapping	Medium Scale	1:20,000-1:62,500	±2 to 10 m.
High Altitude	Small Scale	>1:62,500	>10 m.

Resource potential

The use of 3-D color imagery has increased the potential availability of lower cost analytical stereoplotters, which facilitate high productivity for the operator. The BLM in Alaska is photo-interpreting, using color infrared aerial photography, and mapping survey meanderlines in a "heads-up" analytical stereoplotter. The plotter produces coordinates of the turn points on the meanderline as the hydrography is interpreted (Nakazawa, 1986)

Combined Interpretation, Map Compilation, and Analysis

The increase use of computers in photogrammetry has allowed for several operations to be combined into one system. With these systems, the operator can photo-interpret, map the location, and then spatially analyze the data in a single system. The USGS Geological Divison, Denver has been developing and refining this technique for over 15 years (Pilmore, 1981). The Bureau of Land Management in Wyoming has developed a coal mine production verification system that uses photogrammetry with ground control in combination it with a coal drill hole geologic data base to produce precise 3-D models. Parcel volumetric analysis when overlaid digitally with lease boundaries produced from GPS coordinates of cadastral survey corners. There is very high potential for resource use of systems that combine locational science tools, such as photogrammetry, with cartographic modeling used in GIS.

OTHERS

Digital Superposition Systems

Several vendors offer stereoplotters capable of overlaying (super-positioning) digital data bases and imagery simultaneously, thus allowing the user the additional intelligence of the existing data base in their photo interpretation. Current systems cost over $100,000 but recently they have been decreasing in cost. The most common use of these systems is change detection, i.e., detecting and updating the data base for new roads on new aerial photos. But more sophisticated uses can being applied,i.e., projecting interpreted drill hole well log geology to the surface expressed on color aerial photography to better map faultlines (Pilmore, 1981). Other uses could include a wildlife biologist's superposition of vegetation type maps from a GIS file onto new aerial photos used to interpret and map wildlife habitat interacting with the existing data base. The results will be in the geographic coordinates of the existing data base. Satellite imagery superpositioning has yet to become operational in GIS, but could greatly aid the integration of data analysis.

Others

There are other potential aircraft based systems which collect data on the earth's surface, but are not primarily used as locational devices. Airborne laser profiling can be used to produce elevation control for mapping operations. Synthetic Aperture Radar (SAR) with digital geometric corrections can be used to locate many types of resource data, but it is costly and not widely available at this time.

SPACE REMOTE SENSING SYSTEMS

Remote sensing in support of natural resource mapping has the potential to add synoptic coverage to the common thread of locational science. Besides its use as an inventory tool, remote sensing

has the ability, with superposition of geometrically corrected space imagery and existing digital GIS data, to become both a maintenance and quality control tool. Visual editing of superposition space imagery with vector GIS data on high resolution color graphic workstations will provide a visual review of change detection. The effectiveness of this new technology could be increased with artificial intelligence used to alert the user to potential change.

There are still problems with obtaining adequate maps for geometric corrections. Full positional correction from satellite and sensor empiricals is still developing, and it will take several years before accuracies are adequate. Most remote sensing system analysis software base their adjustments on map coordinate control.

The table below compares the various sensors for mapping accuracy and estimates the maximum mapping scales to use this imagery for resource work.

Sensor Type	*Estimated Scale*	*Resolution*	*Position Accarcy*
MSS	1:100,000	±80 meters	±80 meters
TM	1:100,000	±30 meters	±30 meters
ETM	±1:50,000	±15 meters	±15 meters
SPOT	±1:25,000	±10 meters	±10 meters
Soviets	±1:25,000	±5 meters	unknown

Although several studies state mapping accuracy test results in measurements less than one pixel for that sensor, the minimum resolution cell, this author feels any positional measurement results smaller than the sensor's pixel size should be treated as approximate.

LANDSAT

System description

Over the last 25 years remote sensing scientists have been making geometric corrections of Landsat's Multi-Spectral Scanner (MSS) data positions using map identified locations coordinates for ground control points (GCP). Recent estimates of locational accuracy of MSS using GCPs have produced residuals errors of ±0.23 and ±0.26 pixels (Welch,1985). Welch also reported data from this system could meet the National Map Accuracy Standards (NMAS) for 1:50,000 scale or smaller maps and is well suited for image maps of 1:100,000 scale (Welch,1985). However this author is reluctant to state accuracies of better than ±80 meters for resource data, which would place it in the 1:100,000 scale map products for NMAS.

The Thematic Mapper (TM) sensor in Landsat has been tested to positional accuracies as high as 20 meters RMS (Goodenoug, 1988) with high potential for use in a GIS. Swan, et al., 1988 in a recent study stated that with 4 to 6 GCPs per scene, geometric corrections in the sub-pixel range could be obtained. This would approach 1:50,000 scale mapping accuracies with TM data.

Ehlers, M. and R. Welch, 1987, reported Thematic Mapper RMS accuracies for DEMs in the ±42 meter range and as high as ±25 meters for withheld points from 1:24,000 maps, using a first degree polynomial equation for adjustments. They also reviewed the potential to use only satellite sensor and platform parameters without reference to ground control points and stated, " However, it remains difficult to recover Universal Transverse Mercator (UTM) or geographic (latitude, longitude) coordinates without reference to ground control points." Their results indicate TM's accuracy is good enough for mapping at scales smaller than 1:100,000. Ground resolution ranges from ±30 meters for panchromatic imagery (not positional accuracy) to 120 meters resolution for the thermal images. It is estimated that the Enhanced Thematic Mapper (ETM), scheduled for 1991, will have a resolution around 15

meters, which with GCP geometric corrections should approach 1:50,000 scale mapping accuracies (USGS,1886).

Main uses

Landsat imagery has been used to manually and digitally interpret, map, and locate a large variety of natural and manmade phenomena. MSS has been mostly used for mapping vegetation and other natural resources whose spectral characteristics can be identified on the imagery. Features suffer from the lack of spatial resolution, e.g., the limited size of a pixel, which greatly effects the resultant positional accuracy.

Resource potential

The increased spatial resolution from 80 meters for MSS to Thematic Mapper's 30 meters should provide an excellent resource mapping tool. The Enhanced Thematic Mapper (ETM), with the launch of Landsat 6 in 1991, should provide resource inventory and mapping estimated capability to scales of 1:50,000 (USGS, 1986).

SPOT

System description

The French remote sensing satellite SPOT, while fairly new to the remote sensing scene, is quickly gaining in popularity due to its high resolution potential and more recently for its spatial resolution. SPOT is reported to have a panchromatic resolution of ±10 meters and an MS mode resolution of 20 meters. Swann, R et al, 1988, Rodriquez, et al., 1988, and Goodenough, 1988 report SPOT positional accuracies in the ±10 meter range in x,y, and ±7 meters in z. Konecny, G. et al,1987, appears to varify these measurements and reports SPOT approaches a 1:25,000 scale topographic map in positional accuracy and a 7.5 meter RMS digital terrain model accuracy when using analytical stereoplotter and 1:25,000 scale maps for control.

This author conservativily estimates that accuracies should fall more closely to the accuracies of a 1:50,000 scale map when normal resource map production techniques are used.

Main uses

SPOT's use is similar to that of Landsat, but its increased spatial resolution should enhance SPOT as a resource mapping tool. This increased resolution should assist in detection of change, such as new roads, crops and shoreline changes.

Resource potential

Both Rodriquez,1988 and Goodenough, 1988, report that SPOT satellite imagery can be used to verify both image identifiable base map features and resource data in GIS that was obtained through more traditional techniques, including timber clear-cuts, roads and feature positional errors.

The potential value gained in using large scale topographic maps for control for geometric corrections may be lost in many worldwide locations that don't have maps at 1:50,000 or larger scale. In the Third World areas, where the greatest value of remote sensing and mapping could be gained, positional accuracies would be much lower due to the lack of adequate control. Other point positioning technology, such as GPS or inertial survey systems may eventually become cost effective when used for image identified ground control points(GCP).

SOVIETS & OTHERS

The Soviets have recently stated they have reached a preliminary agreement with a US company to distribute Sojuzkarta color photography and digital imagery at scales ranging from 1:250,000 to 1:25,000 at both 20 meter and 5 meter resolution. This imagery has been reported to have more detail than SPOT or Thematic Mapper data, but mapping accuracy data was not available for this paper. The U.S. contact for this imagery is GeoDyne,Inc., 2201 Scott Avenue, Fort Worth, Texas 76103.

SATELLITE POSITIONING SYSTEMS

Over the last 25 years, locational science has been adding space based telemetry techniques to obtaining ground coordinates. Recently, at a ACSM Convention in St Louis the term "Astrodetics" was used by Dr. Joseph Pelton, Director of Strategic Policy, Intelsat to include measurements and mapping from space. These new passive and active positional space based systems are changing the very nature of locational science to one that can give precise coordinates very quickly on any ground position. Described below are the three currently operational satellite positioning systems available for resource coordinate determination.

ARGOS DCLS

System description

The ARGOS Data Collection and Location System(DCLS) and earlier active satellite telemetry systems have been used over the past 18 years for the identification and location of big game animals and other natural resource phenomenon. This system is a cooperative project of the Centre National d' Etudes Spatiales of France, the National Ocean and Atmospheric Administration(NOAA), and the National Aeronautics and Space Administration(NASA). The ARGOS DCLS uses transmitters operating at the frequency of 401.650MHZ on the ground and receiver instruments aboard two Tiros-N series weather satellites. The system uses the ground station's calculations of the Doppler shift of repeated transmitted signals from one satellite to estimate ground coordinates to mean accuracies of 200-300 meters for known stationary locations.

The use of this system for biotelemetry evolved after 1980 with the production of small transmitters and long lasting batteries. These units weigh approximately 2 kg. when used in a collar for big game. Fancy, S.G. et al., 1988, produced an excellent paper reviewing the ARGOS DCLS capabilities in satellite bio-telemetry. They stated accuracies as "The mean locational error for the combined data set was 829m (±26 SE). Ninety percent of the estimated locations were within 1700m. of true location, and the maximum error was 8.8 km." This paper is a must review for anyone attempting to use this technology (Fancy, 1988).

Main uses

The ARGOS DCLS has been used to obtain both coordinates and data for a large diversity of subjects, including polar bear, grizzly bear, gray wolves, mule deer, walrus, caribou, mustoxen, Dall sheep, elk, sharks, sea turtles, dolphins, whales, bald eagles, ocean buoys, drifting ice, ships and yachts, and etc (Fancy, 1988)

Resource potential

This system has the potential to obtain stationary positions within 235 to 320 meter RMS, with moving objects at better than ±800 meters as reported in Fancy, S.G. et al, 1988. These seemingly low accuracies for biotelemetry are excellent when compared to the cost of ground based monitoring systems. Costs for start up in this operational technology are less than $10,000, including a transmitter and reception and coordinate calculations service. Because the ARGOS DCLS is an active system, it can be used to transmit limited amounts of data to the satellite and then to the ground station.

TRANSIT "DOPPLER" SATELLITE

System description

The TRANSIT positioning satellite system was developed by John Hopkins University Applied Physics Laboratory for the US Navy Navigation Satellite System. The first prototype was launched 27 years ago in 1961. The TRANSIT system was declassified and became available for domestic use in 1967. (Wells, 1986) TRANSIT is a passive system requiring a ground receiver for the user, the TRANSIT satellite, and satellite tracking and control facilities. The TRANSIT system uses the Doppler shift measured at a known station, and remeasured at an unknown position. Satellite parameters are then applied to

calculate ground coordinates of the unknown position. Six TRANSIT satellites are fully operational and transmit data on two carrier frequencies (Stausell, 1978) BLM's TRANSIT operations require approximately 48 hours on station using four or five ground receivers in a differential mode, with one receiver on known geodetic control. The satellite transmissions are recorded on a tape drive for later processing. All "Doppler" coordinates are derived through post-processing in the office, making costly revisits to the field necessary to correct errors detected in post processing (Wells, 1986).

Main uses

BLM's primary use for the TRANSIT positioning system is for obtaining control coordinates for our landnets. We obtain a Doppler control coordinate on each township corner for processing in the Bureau's PCCS software described above in section VI. PCCS calculates coordinates for all survey corners within a township. TRANSIT data can also be used for engineering survey control, control for photogrammetric aero-triangulations, precise locations for valuable point on linear coordinates, such as long pipelines or powerlines. BLM has used Doppler to precisely locate valuable coal drill holes. The accuracy of TRANSIT measurements is dependent on the number of satellite passes observed,and our 48 hour observations obtain accuracies of approximately one meter for occupied stations.

Resource potential

The TRANSIT system is only cost effective for geodetic point positioning control. The satellites are scheduled to be operation until 1994. The Air Force's NAVSTAR GPS is planned as its replacement (Wells, 1986).

NAVSTAR "GPS" SATELLITE

System description

The NAVSTAR (NAVigation Satellite Time And Ranging) Global Position System (GPS) is currently under operational development by the U.S. Air Force as the replacement system for the TRANSIT "Doppler" system in the early 1990s. Ten satellites have been launched and six are operational. The NAVSTAR system is operated similar to the TRANSIT system with a final configuration of 18 operating satellites and three spares in orbit. The control system used for time synchronization and orbit prediction is located at the Consolidated Space Operations Center at Colorado Springs, Colorado. The receivers consist of an antenna with groundplane, a GPS receiver unit, a portable microcomputer, and the power supply. The Motorola Mini-Ranger GPS Eagle Geodetic System can be field backpacked with enough power for one field session. Our current field experience with three GPS receivers has shown them to be more productive and accurate than the TRANSIT systems. The current limited constellation of six satellites gives an observations window of approximately four hours. When all 18 satellites are operational in late 1990, a 24 hour window will be available. The NAVSTAR system will have two code signals available, the R code for U.S. military use and the C/A code for civilian use. Instantaneous positioning capability is available, but at greatly reduced accuracies (Wells, 1987).

Main uses

The main use of GPS is to provide military air, sea, and ground units with a unified, high precision, all-weather, instantaneous positioning capability. The GPS has been made available for civilian geodetic use, but with reduced capabilities. The BLM plans to use GPS for cadastral survey coordinate calculations as described above in the TRANSIT satellite section. Accuracies for GPS have been tested by the National Geodetic Survey (NGS) to geodetic quality, ±1 centimeter. The normal user should obtain results with geodetic quality receivers in the range of 10 centimeters to ± one meter in a normal field operation.

Resource potential

Recent releases of new systems have greatly reduced the cost and size of GPSs. Trimble Navigation has a new system for resource data positioning that can be handheld; the GPS

receiver weighs less than 3 lbs. Trimble states the differential positioning capability of 3 to 5 meters. The estimated unit cost is $20,000. Other companies should soon follow with very small non-geodetic systems and small field portable geodetic units.

Accuracy claims of GPS keep improving. Remondi, B.W., 1986 produced RMS results using kinematic surveying techniques of 0.6 cm. in latitude, 1.0 cm. in longitude, and 2.6 cm. in height using GPS. He stated " Not only does this permit real-time centimeter level surveying in seconds, but also it would allow the user to navigate to within centimeters of a desired location in real time." (Remondi, 1986).

ELT's

The Emergency Location Transmitter's(ELT) system uses both aircraft and satellite receiving systems to identify aircraft and ship accident site locations. These small transmitters are required in all US registered aircraft. The SARSAT/COSPAS system has five satellites, two U.S. and three Soviet. They monitor the ELT emergency frequencies and locate the transmission to within approximately one kilometer. This system has limited resource use at this time due to the single emergency use of these systems.

GEOSTAR & OTHERS

Several commercial two way (active) positioning systems are in the planning stages. One, GEOSTAR, has undergone some initial testing. GEOSTAR is proposed as the first continent-wide communication and locational system. It is targeted at the transportation industry for identification, location monitoring, and communication to commercial vehicles, and for control signals to Vehicle Navigation Appliances (VNA) proposed for electronic horizontal situation displays in automobiles. GEOSTAR will provide subscription services. Estimates of the transceiver costs are less than $500.00 with volume sales. Accuracies for this system are unknown but ±10 to 50 meters could be expected. In comparison, current non-geodetic GPS systems cost $20,000 and have autonomous positional accuracies of ± 25 meters.

The European Space Agency has proposed NAVSAT, a commercial positioning system similar to GPS. This system is proposed to have three classes of users: navigation accuracy, high accuracy, and geodetic accuracy (Wells, 1987).

The Soviets have a 12 satellite GPS equivalent, GLONASS, designed as a one-way military system. Soviet civilians have access to their GPS systems (Wells, 1987) for point positioning.

RECOMMENDATIONS

1. If your data is identifiable on aerial photography , then manual transfer of data to overlays on an orthophotoquad would be the most effective technique to locate data.

2. When documented legal descriptions and ground measurement are required use cadastral ground surveys with ties to geodetic control or GPS positions.

3. If precision coordinates are required, use geodetic quality GPS systems.

4. Photogrammetry is the most cost effective tool for precise coordinates of polygon data.

5. Manual transfer of data from aerial photos to topographic maps produces lower accuracies when compared to photogrammetry.

6. If terrain is important in locating your data, then topographic maps or photogrammetry should be used.

7. Consider all spatial analysis needs prior to selection of a locational technique. When a

sub-centimeter data set is combined with 20 meter data, both cost effectiveness and accuracy are lost.

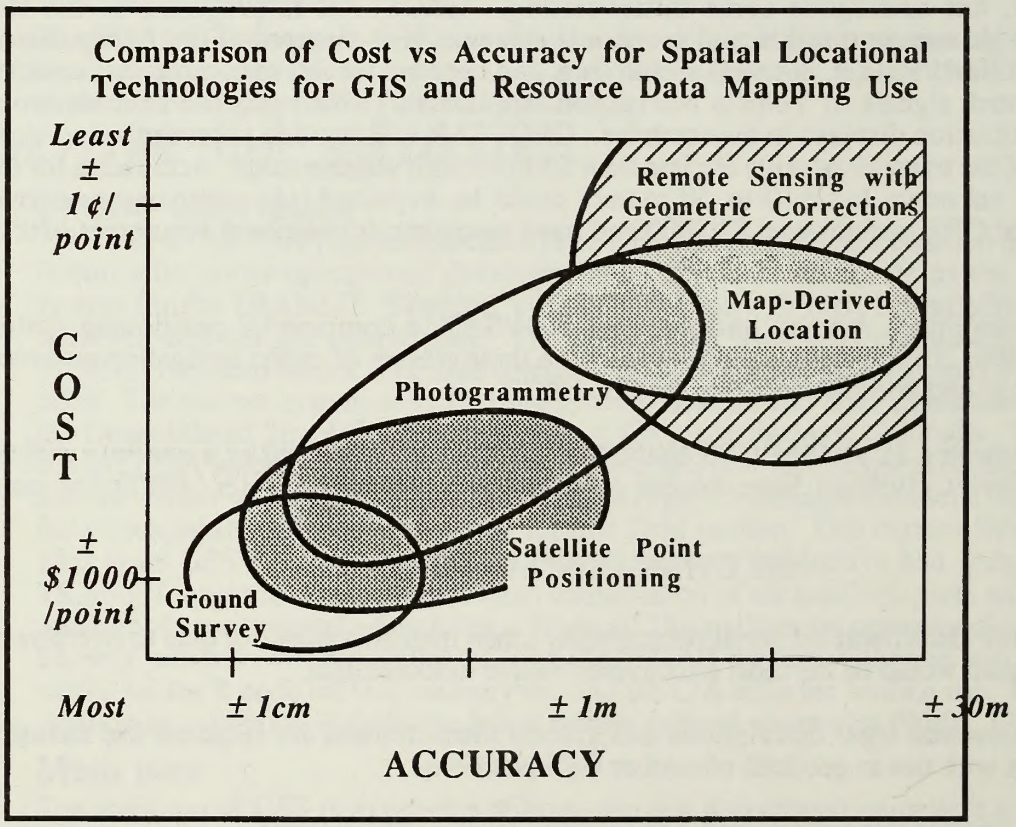
8. Low cost scanning systems can degrade the positional accuracy of data.

9. Plan ahead for the source of your resource location coordinates when planning a GIS data base. Many projects have failed because they did not identify the mapping accuracy requirement until late in a project. Identify minimum project accuracy requirements. Select practical and realistic accuracies. For example mapping soil types with current GPS technology is not practical.

10. Try to reduce long-term costs. If the initial project requires only cartographic accuracies, but future uses require geodetic coordinates of very high value resource data, consider GPS and/or photogrammetry.

11. Costs are normally reduced if you capture coordinates as you collect data. The graphic below compares the relative accuracies of five location systems used to position resource data for a GIS.

Figure 2



THE FUTURE

Predictions of the future for resource locational tools are very difficult to make. While the basic technology remains the same, increases in computer and electronic capabilities can greatly reduce the cost, increase the accuracy and reduce the size of all positional systems.

1. Increased commercial activity and a combination of commercial/international government competition in non-resource fields will give resource managers access to new locational technologies.

2. The sub-meter, handheld, $500.00 active field positional system is less than five years away.

3. Geodetic systems will produce centimeter accuracy in seconds.

4. Superposition will be available on all steroplotters, combining digital and photogrammetric data.

5. Desktop analytical photogrammetric devices will be available for less than $25,000 in a few years.

6. Artificial intelligence rule-based systems will assist in scanned resource data edits.

7. Combined real-time data and location collection in handheld field data recorders will be available prior to the printing of this paper.

8. Handheld electronic navigational maps at VCR prices will be available in less than 10 years.

The location of resource data is very important in the design of an integrated resource data base for use in spatial analysis systems. One of the above locational tools will provide the correct economies and accuracies to meet most, if not all, resource manager's needs. The basic techniques reviewed in this paper have been used for over 25 years, while the newer exotic procedures are being operationally tested and used daily by many technicians and scientists. Technologies are now available for all accuracy levels and needs of potential users.

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APPENDIX E

DRAFT GPS COURSE OUTLINE
March 15, 1991

I. Introduction
- A. Course Objectives
- B. Overview of Positioning Systems
  1. Conventional Ground Survey
  2. Photogrammetric
  3. Doppler
  4. Transit
  5. Loran
  6. Inertial
  7. VLBI
  8. GPS
     - a. Navstar
     - b. Glonass
  9. Geostar
  10. Integrated Positioning

II. Basics of GPS
- A. Purpose/Development
  1. Doppler Theory
  2. Driven by need for Real-time Positioning
  3. Civilian Applications
- B. Configuration of GPS
  1. Space Segment
     - a. Number of Satellites
     - b. Orbit Planes
     - c. Signal Structure
       - i. Message
       - ii. Encryption (SA, etc.)
  2. Controller Segment
     - a. Operational Control
     - b. Systems Controlled
       - i. Signal
       - ii. Orbit
  3. User Segment
     - a. Military
       - i. Aircraft, Ships, & Trucks
       - ii. Ordinance Delivery
     - b. Civilian
       - i. Land, Sea, & Air
       - ii. Surveying
     - c. Research

- C. Limitations
  1. Physical Limitations
     - a. Satellite
       - i. Signals (broadcast)
       - ii. Orbits
     - b. Ground Station
       - i. Obstructions
       - ii. Multipath
       - iii. Receiver/Antenna Type

2. Other Limitations
    a. Horizontal Accuracy Requirements
    b. Vertical Accuracy Requirements
    c. Distance Limitations

III. Review of Geodetic Concepts
A. Geoid and Ellipsoids
B. Reference Systems
    1. WGS Reference Systems
    2. NAD Reference Systems
    3. NAVD Reference Systems
C. Coordinate Systems and Projections
    1. Lat, Long., Ht., & Elev.
    2. Geocentric
    3. State Plane, Local, UTM
    4. Projections

IV. Elements of GPS
A. Positioning Techniques
    1. Site Location
    2. Navigation
    3. Surveying
    4. Geodetic Surveying
B. General Capabilities
    1. Absolute Positioning
    2. Relative Positioning
        a. Static
        b. Kinematic
        c. Pseudo-kinematic
    3. Time Transfer
C. Applications
    1. Resource
        a. Mapping
        b. Location
    2. Cadastral
        a. Corner Search
        b. Azimuth Determination
        c. Distance Determination
        d. Control Surveys
    3. Geodetic
        a. Photogrammetric Control
        b. High Precision Networks
        c. National Geodetic Control Network
    4. Data Bases
        a. GCDB
        b. GIS/LIS
    5. Scientific
        a. Plate Tectonics
        b. Subsidence
        c. Extra-terrestrial
    6. Transportation
    7. Base Stations

APPENDIX E

V. GPS Systems Overview
- A. Hardware
  - 1. Navigation Grade
  - 2. Geodetic Grade
  - 3. Integrated Systems
- B. Third Party Software
  - 1. Network Adjustment
  - 2. Datum Transformation
  - 3. Geoidial Separation Determination

VI. GPS Field Operations
- A. Standards and Requirements
  - 1. FGCC
  - 2. BLM Cadastral
    - a. Control Surveys
    - b. Surveys/Resurveys
- B. Mission Planning
  - 1. Research
  - 2. Satellite Visibility
- C. Data Collection
- D. Post-processing
  - 1. Baseline Determination
  - 2. Network
- E. Analysis

VII. Supporting Information
- A. User Support
  - 1. Government Agencies
    - a. NGS
      - i. Phone
      - ii. E-mail
    - b. Coast Guard
      - i. Phone
      - ii. Bulletin Board
    - C. BLM
  - 2. Manufacturers
- B. Glossary
- C. Supporting Reference Material
  - 1. Bibliography
  - 2. POB Equipment Survey
  - 3. Journals
  - 4. Additional Training

VIII. Summary, Wrap-up, and Evaluation

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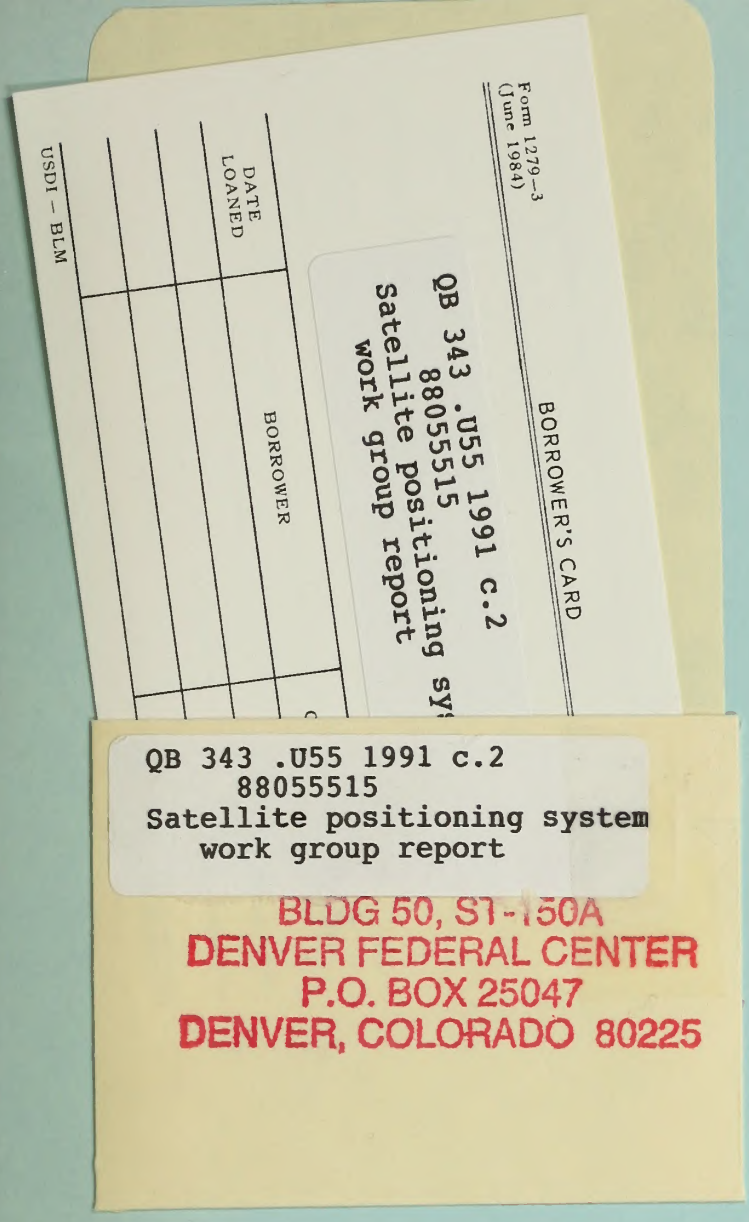

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